THE VALUATION OF AGRICULTURAL BIOTECHNOLOGY:

THE REAL OPTIONS APPROACH

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The Valuation of Agricultural Biotechnology:

The Real Options Approach

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ABSTRACT

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This study develops a real options model of agbiotechnology and is applied to three genetically modified (GM) traits. Each trait is evaluated as growth options where technical or marketing milestones must be completed before management can exercise the option to invest further in trait development. The real options values are evaluated by employing a binomial tree which is simulated using distributions for random elements within stages of the growth option. Mean option values were negative for the discovery stage for fusarium-resistant wheat and for all but the regulatory submission stage for Roundup Ready wheat. The length of the regulatory submission stage had the greatest negative impact on the value of the option while the ability of the firm to maximize technology-use-fees had the greatest positive impact. Additionally, traits adapted to crops with larger potential market size are more likely to be in the money than traits developed for smaller market segments.

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STATEMENT OF PROBLEM

Introduction

Innovation is about acquiring new knowledge regarding underlying physical processes and products. The industry of agriculture has used innovation to increase productivity through mechanical, chemical, and biological advancements (Fernandez-Cornejo, 2004). Research and development has led this surge and is forging the industry ahead to more complex biological and physical systems. The most significant progression in agricultural innovation has been the introduction of genetic manipulation in plants, animals, and microorganisms.

Genetically modified (GM) crops can be classified as meeting needs in crop productivity (input trait), food and bio-processing (output trait), or nutraceuticals and pharmaceuticals (health or medicinal traits) (McElroy, 2003). Thus far, the only crops to enter commercial markets are those with input traits. Such traits include herbicide-tolerant (Ht) and *bacillus thuringienisis* (BT) resistant traits; both are designed to reduce farmers' costs and increase crop productivity.

Being able to quantify the value of these new technologies, even those still in development, is important to accountants, buyers and sellers of licensing agreements, investors, patent holders, financial managers, and executives. Decision makers must allocate finite budgets to projects that will maximize their firms' long-run profitability. Thus, the accuracy of valuation is a critical function in operational efficiency and shareholder value.

The focus of this thesis is valuing agbiotechnology through the product life cycle. Instead of using traditional valuation methods, this study uses the real options approach.

The traditional discounted-cash-flow framework values an asset by discounting its expected future cash flows by a predetermined discount rate. However, the traditional framework ignores the value of options associated with contingent decision making. Real options account for this value and the opportunities created from uncertainty.

Problem Statement

Strategic planning and investment are critical functions in the operation and profitability of a business. The agbiotechnology sector is no exception. Firms commit substantial capital to the development of a new GM trait in hopes of creating exploitable profit opportunities. However, the process is not a onetime strategic decision, but there are options embedded in the process and value associated with managerial flexibility.

Ongoing investment in research and development for agbiotechnology is a long-run process with serious strategic implications. Thus far, most research has considered the societal implications of the adoption of GM crops and food. These studies relate well for regulatory and trade agencies, but contribute little to research strategies developed by firms. The valuation of the product development cycle is complex because the process takes eight to 10 years to complete, and during this period investments are made with the knowledge that the effort has a high probability of failing. In addition, there is uncertainty about the costs of development and cash flows received post commercialization.

The real options approach provides a way of modeling the uncertain values underlying the investment in a GM trait. In this case, the unknown values are the expected cost to completion and the expected cash flows after commercialization. Uncertainty is introduced, because these variables change over time, and are dependent on the particular characteristics of the GM trait.

Elements of the Problem

Two primary problems are associated with valuing the agbiotechnology development cycle. First, the expected post commercialization cash flow has many uncertain characteristics. The trait developer must be able to accurately forecast product demand based upon domestic and international adoption rates. In addition, industry structure affects the uncertainty with competing products and the technology fee charged for GM seed. Accounting for product demand and price are complex in their own right; however, they are needed in order to develop an accurate valuation framework.

The second problem is the cost of developing a new trait and the technical and regulatory uncertainty associated with production. Each phase in the development process has specific risk and cost attributes that are dependent on the individual trait. Therefore, developing a useable framework for analyzing, comparing, and evaluating numerous traits must account for these uncertainties.

Producer Demand for Genetically Modified Seed

Domestic Adoption

Demand for GM crops has been significant due to the producers' potential to lower input costs, ease production, and provide specialized output characteristics. Figure 1.1 illustrates the considerable growth in the adoption of Ht and Bt varieties in the United States. The use of Ht and BT soybeans grew from 7% of acres planted in 1996 to 81% in 2003; Ht and BT corn use grew from 4% in 1996 to 40% in 2003; Ht and BT cotton use grew from 17% in 1996 to 73% in 2003 (Runge and Ryan, 2003). Figure 1.2 illustrates the success total domestic planting percentage of adoption of GM corn, cotton, and soybeans.

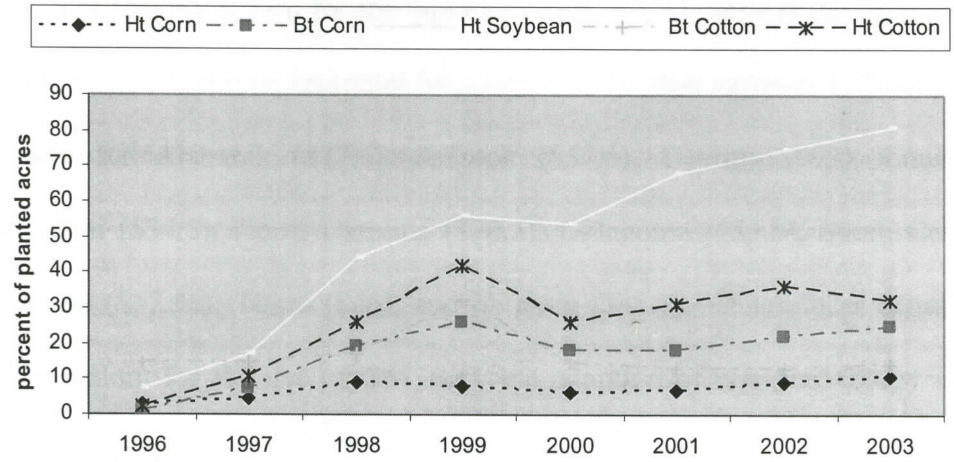

Figure 1.1. Percent Planted Acres of BT and Ht Varieties.
Source: Fernandez-Corejo (2003).

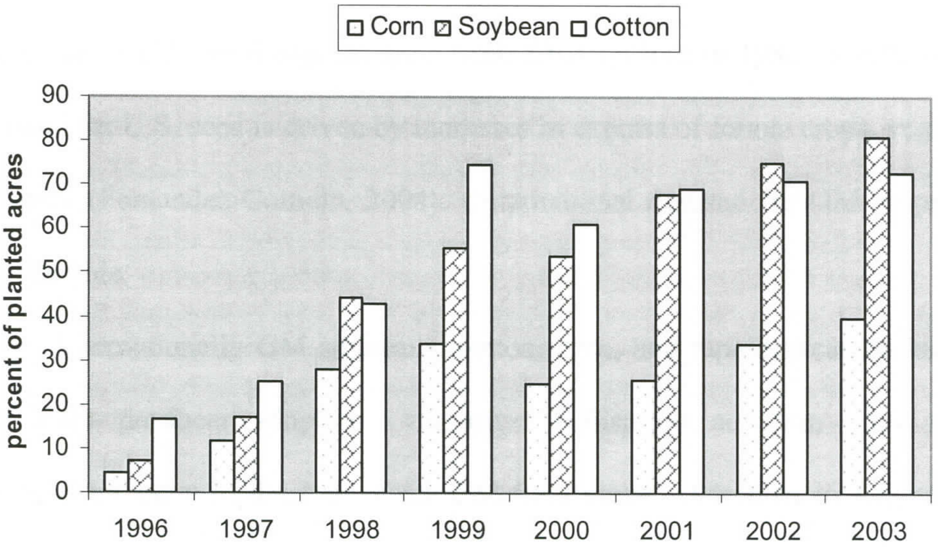

Figure 1.2. Total Domestic Planting Percentages in GM Crops.
Source: Runge and Ryan (2003).

There have also been developments in rapeseed/canola; however, the USDA does not track GM planted acres for those oilseeds. Runge and Ryan (2003) estimate adoption rates to be around 70% in 2003. Numerous other GM crops have also been developed, including rice, wheat, potatoes, and sugar beets, but have not been commercialized due to deficient demand and regulatory constraints.

The leading reason for the rapid adoption of GM crops is the benefits they provide producers. For example, estimates by state for BT cotton varieties include increased profit per acre for Alabama ($77.6), Arizona ($57.5), Georgia ($92), Louisiana ($16.5), Mississippi ($34.5), North Carolina ($20.5), Oklahoma ($53.8), South Carolina ($51.8), Tennessee ($67.50), Texas ($46), and Virginia ($41.7). If producer benefits exceed the price premium for the use of GM seed, the adoption of new technology is justified and should continue.

International Adoption

The United States (U.S.) is a large exporter of seed to numerous foreign markets. The value of U.S. seed exports grew from $305 million in 1982 to $698 million in 1996. Demand for U.S. seed is driven by increases in exports of forage crops, vegetables, flowers, and corn (Fernandez-Cornejo, 2004). International demand for GM crops has also been considerable.

Internationally GM soybeans, cotton, corn, and rapeseed/canola have experienced significant producer adoption. Figure 1.3 displays adoption rates for the largest international users of the four major GM field crops. Adoption in Argentina reached 34 million planted acres; followed by Canada with 11 million planted acres, Brazil with 7 million planted acres and China with 7 million planted acres. These four countries, plus the United States, make up 98% of GM planted acres in the world (Runge and Ryan, 2004). Typically, the U.S. is the leader in adoption, and smaller countries use a wait-and-see approach in making their adoption decision.

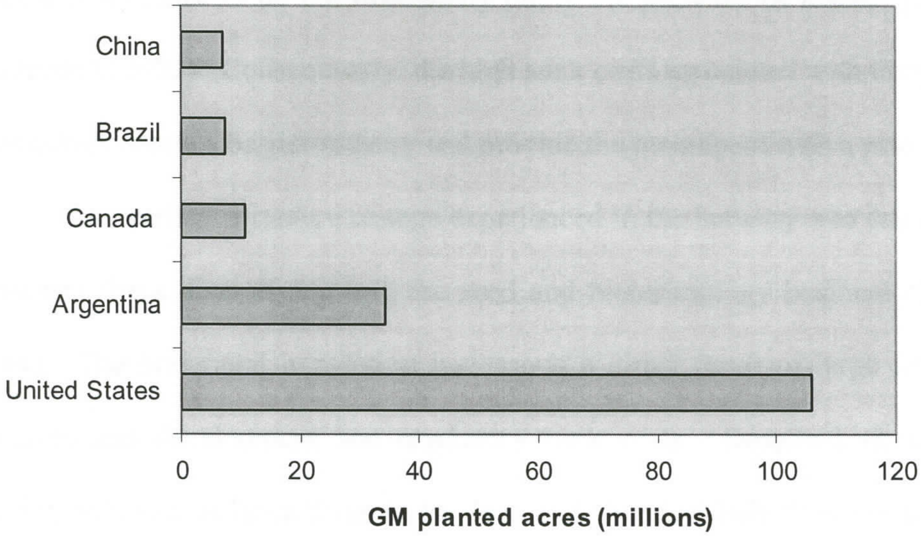

Figure 1.3. International GM Planted Acres.
Source: Runge and Ryan (2004).

Agricultural Biotechnology Industry Structure

Traditionally, agricultural research and development was almost entirely within the confines of public institutions. However, advancements in biotechnology, strengthened intellectual property rights, and the expansion of open global markets has been the motivation behind increased private expenditure (Klotz-Ingram and Day-Rubenstein, 1999). The commercial success of input traits has led to continued research and development spending into identifying new traits and the establishment of new markets.

The agbiotechnology industry is one of the most concentrated in the world. There are hundreds of small firms, but the market is controlled by six large multinationals: Syngenta, Bayer, Monsanto, DuPont/Pioneer Hi-Bred, Dow, and BASF (Runge and Ryan, 2003). High industry concentration, in part, is caused by large research and development and regulatory approval expenditures.

The seed and pesticide industries experienced a substantial number of mergers and acquisitions and an increase in vertical and horizontal integration in the 1990s. However, concentrated markets do not necessarily imply the presence of market power (Fulton and Giannakas, 2001). Consequently, the high sunk costs associated with investing in new GM technology create a barrier to entry and provide the incumbent with a price advantage.

The vertical structure change experienced in the industry was caused by large agro-chemical firms diversifying into the seed and biotechnology business (i.e., Monsanto or Dow). The horizontal integration increase is a direct result of large firms consolidating research and development and regulatory sunk costs. Despite high concentration, the pricing behavior of large firms in the seed and chemical industries are strategic in nature. The pricing of products is influenced by competition from other products and the value created by their own products (Fulton and Giannakas, 2001). However, price discrimination exists through the use of technology use agreements, differential pricing, and tied sales.

Agbiotechnology firms charge technology use fees for the right to use their patented product. Monsanto charges a 5% royalty for their BT variety and a 5% royalty for their Ht variety (Huso, 2004). The price charged is dependent on how many competing technologies are available; thus, it is unrealistic to use a fixed royalty fee throughout the life of the patent.

Adoption rate and the size of the traditional market are used to determine possible sales quantity of GM seed. The adoption rate follows a diffusion process, where over time the value increases but at random increments (Fernandez-Cornejo, 2002). Planted acres of non-GM crops can be used as the traditional market size. The product of the two provides an estimate of possible sales.

Cost of Trait Development

Regulatory and Consumer Response to GM Technology

Despite the wide ranging consumer-and-producer oriented product opportunities, there are significant risks associated with investment in agbiotechnology. Consumer resistance, especially in European countries, has generated concerns about sustained growth in international adoption (McElroy, 2003). Consumers are primarily concerned with potential allergic reactions and long-run environmental impacts.

GM food and feed have also been a contentious issue for domestic and international regulatory agencies. Canada, Japan, Mexico, and the United States generally have approved most of the new GM products for production and consumption. Regulators in Australia, the European Union (EU), and New Zealand, in contrast, have postponed approval of many new GM advancements (Phillips, 2003).

The greatest point of contention is in the labeling systems being produced or developed by various countries' domestic regulators. Argentina, Canada, Hong Kong, and the United States have adopted a voluntary labeling system, while many countries, including the EU, have adopted mandatory labeling on all products with GM ingredients. This has forced adopting countries to shift trade from highly regulated countries to countries with a less stringent regulatory regime.

Nine international bodies, including the World Health Organization, United Nations, and the World Trade Organization, are currently coordinating the regulation of different aspects of food safety (Phillips, 2003). Despite the intervention of numerous groups and agencies, there is no clear view on the overall goal of international regulation. This, along with consumer resistance, makes investing in agbiotechnology an uncertain endeavor. The regulatory approval costs for new GM crop varieties increased from \$5-10 million in the 1990s to \$20-\$30 million in 2003 (McElroy, 2003).

Technical Risk and Cost of Development

Development of each trait follows a five-phase process with each phase containing different cost attributes. The first phase, discovery, is designated for trait/gene identification and experimental investigation into new research venues. It takes between 24 to 48 months to complete, at a cost of \$2-5 million. Only 5% of identified traits make it to the second phase of development (Monsanto, 2004).

The proof of concept phase involves gene configuration and performance screening in a controlled environment. Firms determine the traits that show the most promise for application to core plants with a time horizon of 12 to 24 months. The cost of completion and trait advancement is between \$5-10 million, where only 25% of the traits are selected to advance to the early development phase.

The early development phase for biotechnology products is when firms conduct lab and field testing of genes in plants to select the product candidates for commercialization. They also designate the selected genes for pre-regulatory requirements. Early product development costs firms \$10-15 million and takes 12 to 24 months to complete, and 50% of the traits advance to the next development phase.

In the advanced development phase, firms demonstrate the efficacy of a biotechnology trait in elite germplasm. They also begin developing the appropriate regulatory data. The average duration is 12 to 24 months, costs to complete are \$15-30 million, and 75% of traits advance to the pre-launch stage of product development.

Regulatory submission is the last and most costly phase of development. Firms submit all necessary regulatory information and begin seed bulk-up. The regulatory submission phase takes 12 to 36 months, costs $20-40 million, and 90% of the traits are approved for commercialization.

Hypothesis

It is expected that the real options approach to valuing the agbiotechnology development cycle yields increased project valuations. This increased valuation will exist because the real options framework recognizes management flexibility and the contingent nature of the development process.

Organization

Chapter 2 thoroughly describes GM crops and the firms competing in the industry. A review of previous literature relating to the problems addressed in this thesis is provided. Chapter 3 provides a theoretical description of the foundation of real options model building. Chapter 4 provides an empirical model for evaluating multiple GM traits using the real options framework. In addition to the model, results and sensitivities of key variables are provided. Chapter 5 consists of valuation analysis on specific GM traits using the model developed in Chapter 4. Conclusion, implications, and limitations are presented in Chapter 6.

Methodology

The methodology will include a valuation analysis of GM traits at each phase of development using real options. GM crop data, including numerous varieties and technology fees, will be used in the model. Data on planted acres of traditional crops will be used in conjunction with planted acres of GM crops to estimate expected trait revenue. Currently available traits will be used as a starting point.

Real options analysis is conducted using the binomial model and discrete event simulation. A discrete event system is one in which the variables change only at discrete points in time; whereas a continuous system is one in which state variables change continuously over time. The binomial option valuation model is based on a simple representation of the evolution of the value of the underlying asset.

CHAPTER 2
BACKGROUND AND REVIEW OF LITERATURE

Introduction

The increased private activity in, and subsequent market acceptance of, GM crops and foods has led to research in several areas. There has been substantial work done in the areas of pricing and regulatory mechanisms. In addition, numerous studies have analyzed producer benefits and adoption trends in various GM varieties and crops. The following section presents previous work of importance to the valuation of the agbiotechnology development process. This chapter is organized in three main sections: (1) the status of the agbiotechnology industry, including the competitive environment, research and development investments, and regulation of the industry; (2) previous studies using real options as the valuation methodology; and (3) previous literature on real options applications specifically related to biotechnology and agriculture.

Industry Structure and Conduct

Private Research and Development

Since 1983 the private sector has surpassed the public sector in terms of research and development expenditure on GM related research; however, the public sector still plays an essential function in expanding the scientific stock of knowledge. Furthermore, public institutions can invest in projects where the maturation period is longer because the research is not motivated by market mechanisms and incentives.

However, research and development for GM crops is largely driven by private firms. In 1960, total U.S. public agricultural research spending was 111% of U.S. private expenditure. This trend lasted until 1980 when total U.S. public spending was 92% of total private spending. The trend continued into the 1990s; in 1996 total U.S. public spending was 75% of total private expenditure. Figure 2.1 illustrates total public and private R&D spending and public spending as a percentage of private for time periods 1960-1996.

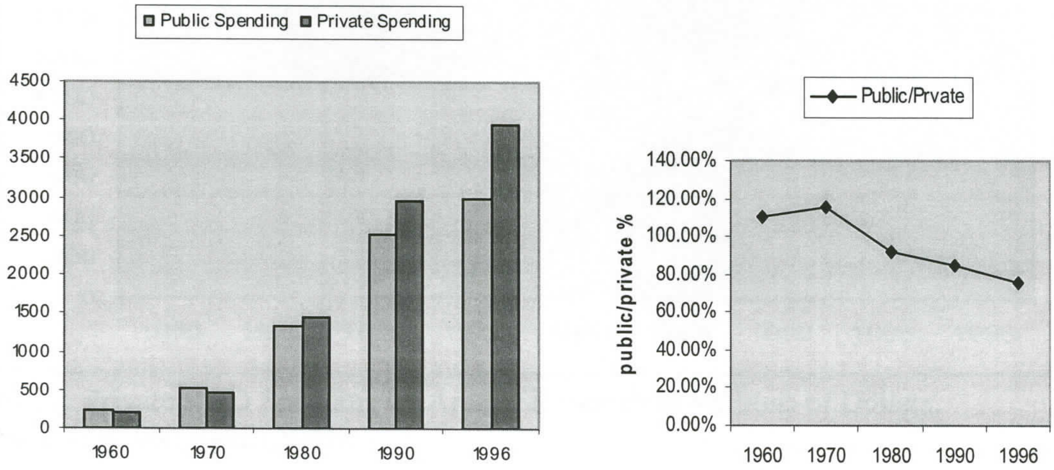

Figure 2.1. Total Public and Private R&D Spending and Public Spending as a Percentage of Private for Time Periods 1960-1996.
Source: Runge and Ryan (2003).

Private sector spending has increased in all four major categories of research and development: chemicals, machinery, plant breeding, and food processing. In 1960, private firms invested $27 million in research and development for agricultural based chemicals. That number increased to $1,459 million in 1996. Figure 2.2 displays spending by private firms for plant breeding compared to the other three important investment categories including chemicals, machinery and food processing.

Private expenditure has shifted heavily from machinery and food processing to agricultural chemical and plant breeding research. Moreover, the proportional increase in chemical spending is still greater than the spending for plant breeding. This can be attributed, in part, to the fact that research in agricultural chemicals has long been dominated by the private sector, while plant breeding was traditionally the domain of the public sector (Fernandez-Cornejo, 2003).

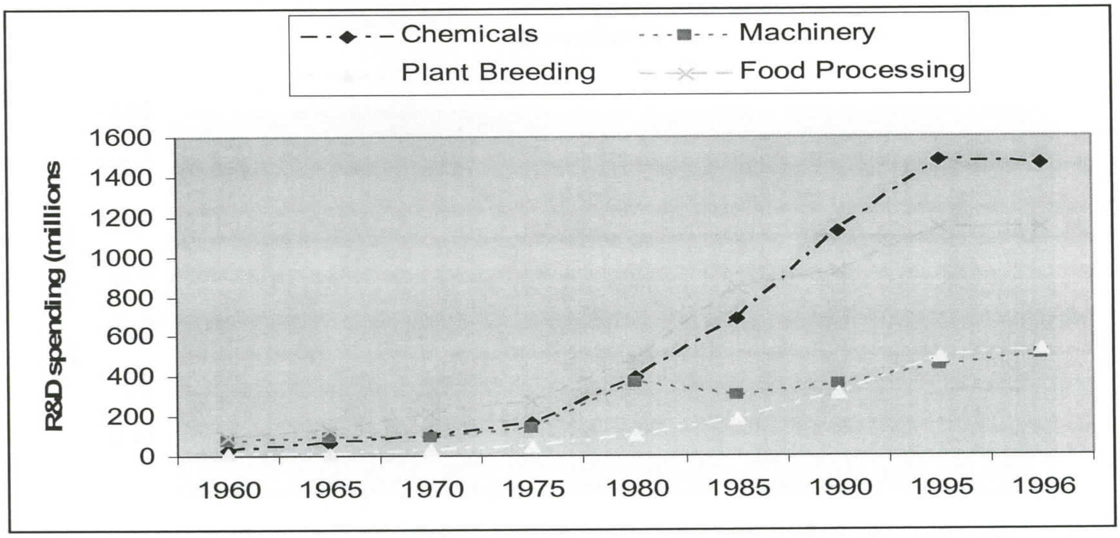

Figure 2.2. Private R&D Spending by Area of Research in Millions of Dollars.
Source: Runge and Ryan (2003).

Decisions about research and development made in a competitive environment are likely to differ from investment decisions made in the public arena. The driving force behind the increase in research and development in plant breeding, from private interests, is the emergence of modern biotechnology. Research and development activity can be tracked by applications to the USDA's Animal and Plant Health Inspection Service (APHIS) for field testing trials.

Private companies proposing tests with GM organisms in the environment must notify APHIS of their intent, in accordance with the field release notification procedures, or submit an application for a field release permit (Fernandez-Cornejo, 2003). APHIS reviews the application to determine any environmental risks associated with the release. The procedure is not incredibly stringent with approval. Figure 2.3 illustrates APHIS field trials from 1987 to 2001. APHIS received 7,600 applications and approved the release of 6,700 new traits. The growth in applications has been incredible; in 1987 APHIS received only nine applications compared with the 1,206 received in 1998.

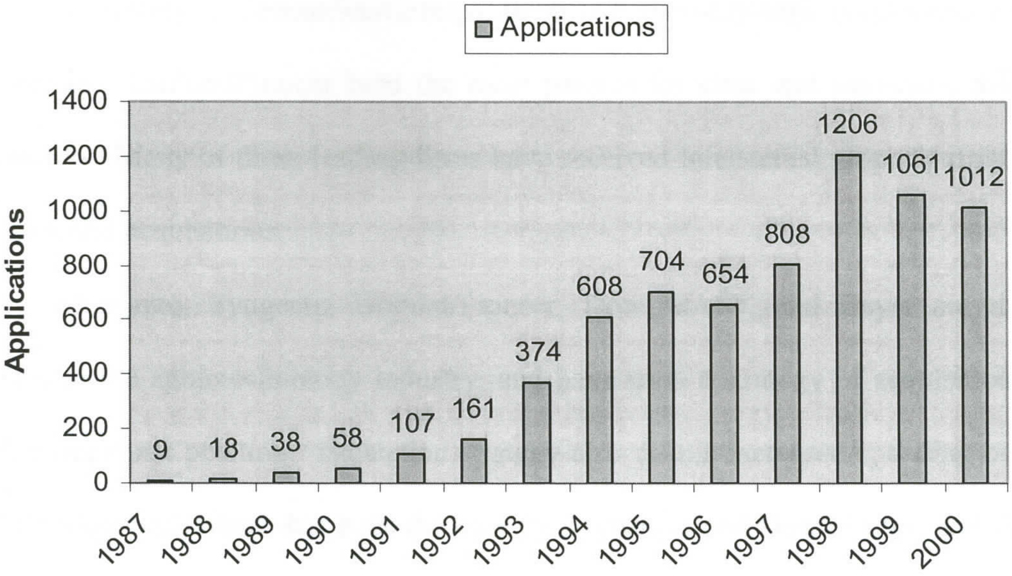

Figure 2.3. Field Trial Applications to APHIS Between 1987 and 2000.
Source: Fernandez-Cornejo (2003).

Research into new corn varieties has been, by far, the most extensive of all GM crops. Between the years of 1987 and 2001, there were field test applications for 3,327 different corn varieties. The second most researched crop variety was the potato, with 761 field trial applications. Soybeans (601), tomatoes (532), cotton (481), and wheat (209) were also highly researched during the same time period.

Competition in Agbiotechnology

A relatively small number of firms are active in the field crop biotechnology sector. Typically, industrial concentration is measured by output variables, such as sales. However, Fulton and Giannakas (2001) suggested using the four-firm concentration ratio for APHIS field trial releases as an alternative measurement. Using this method, Fernandez-Cornejo (2003) found the four-firm concentration ratio for corn is 72%, for soybeans is 84%, and for cotton is 96%. The high concentration in research and development can create high barriers to entry for competing firms.

According to Fernandez-Cornejo, there is a similarly high concentration in patent ownership. DuPont/Pioneer held the most patents for corn and soybeans, followed by Monsanto. Many of these leading firms have received intellectual property rights through mergers and acquisitions.

Monsanto, Syngenta, DuPont/Pioneer, Dow, BASF, and Bayer are the largest players in the agbiotechnology industry, and have used a strategy of acquisition to attain such a dominant position. Escalation strategy also entails increased spending on research and development, which has been the case for Monsanto and Dow (Fulton and Giannakas, 2001).

Monsanto was primarily an agricultural chemical company in the early 1990s until it began to acquire firms in the seed production and distribution business. Monsanto purchased Asgrow, Calgene (first firm to commercialize a GM food in the U.S.), Dekalb, and Carrgill's international seed business. Monsanto also purchased numerous biotechnology research companies, such as Ecogen, Agracetus, and the Plant Breeding Institute. Monsanto eventually merged with the pharmaceutical giant Pharmacia, and in 2000 become a publicly traded company. Monsanto retains the greatest market share in agbiotechnology (Fernandez-Cornejo, 2004).

In 2000, Syngenta was created through the merging of Novartis' crop protection and seed business with AstraZeneca's agrochemical business. The Novartis side of the merger provided American seed distribution through the Northrup-King subsidiary and biotechnology advancements through Ciba-Geigy and Sandoz. Novartis was the accumulation of (approximately) 20 smaller seed and life science companies. The AstraZeneca side of the merger provided advanced capacities in biotechnology.

Chemical conglomerate DuPont purchased Pioneer in 1999 to take a foothold in the biotechnology industry. Through Pioneer, DuPont has advanced in a strategy of focusing on the commercialization of new generations of food, feed, and nutrition products developed with biotechnology (Fernandez-Cornejo, 2004). DuPont also acquired Dalgerty, Hybrinova, and Cereal Innovation Center.

In 2002, Bayer acquired agriculture company Aventis CropScience, forming Bayer CropScience. BASF purchased American Cynamid from American Home Products in 2000. Dow Agrosciences entered the biotechnology industry through the purchase of Mycogen.

Despite concentration, the top six firms have conducted research and development on numerous competing products *in* all major field crops. In corn, Monsanto has eight different traits, Bayer has four, and Syngenta, Dow, and DuPont have two varieties each. In soybeans, Bayer, DuPont, and Monsanto all have competing Ht products. In cotton, Monsanto is testing five different varieties; the only competing research is being done by Bayer and BASF (one variety each). Finally, in rapeseed/canola, Bayer CropScience dominates with Ht and output traits with increased fertility levels.

Industry Regulation

There are numerous areas of regulation, most of which have a well-developed body of literature and are of importance to a firm's strategy. Regulations include the areas of domestic and international labeling laws and points of contention between countries and regulatory agencies. The appropriability of intellectual property rights on GM organisms as a mechanism for monopoly revenue generation is also a controversial factor. There are also issues in environmental norms, traceability, and segregation.

According to Sheldon and Josling (2002) there are two primary methods of GM crop regulation: (1) countries can use an *equivalence principle* where they rely on scientific consensus or (2) countries can use a *precautionary principle* and be more proactively cautious about health and environmental implications. The difference in these two philosophies has led to differences in regulation in the United States and in the European Union.

The two alternative regulatory philosophies have led to differing approaches to laws concerned with the labeling of GM foods. Countries following the *precautionary principle* have pushed for mandatory labeling of all GM foods, which implies that the product is experimental and consumers should be warned about potential hazards. Countries following the *equivalence principle* recommend voluntary labeling of GM foods, which in most cases implies "GM-free" foods.

The *equivalence principle* or "substantial equivalence" was set to determine if the GM food presents any new or additional risks in comparison with its traditional counterpart, or whether it can be used interchangeably without affecting the health or nutritional status of consumers. The noted goal is to establish the relative safety of the new product such that there is a reasonable certainty that no harm will result from unintended uses under typical conditions. The *equivalence principle* was developed by the Organization for Economic Cooperation and Development and later endorsed by the World Health Organization and the U.S. Food and Drug Administration.

Key GM adopting nations, such as the U.S. and Canada, are shifting trade from over-regulated countries to countries with a more lenient regulatory regime. For example, U.S. corn exports to the EU have fallen 70% in recent years, soybeans have fallen 48%, and Canadian exports of canola have dropped 96% (Phillips, 2003). There is the potential of serious distortion in trade flows that will offset many of the benefits of recently agreed upon trade negotiations.

The most important regulatory aspect of agbiotechnology is the protection of new technology through intellectual property rights. Passing of the Plant Variety Protection Act (PVPA) in 1970 led the way for modern agbiotechnology intellectual property law. PVPA grants plant breeders a certificate of protection that gives them exclusive rights to market a new plant variety for 18 years from the date of issuance (Fernandez-Cornejo, 2004). However, PVPA allowed for research exemptions and a farmer's exemption that permitted the saving and reproduction of GM seeds.

Subsequent amendments to PVPA prohibited any reuse or reproduction of GM seed unless authorized by the patent holder. The advancements of intellectual property protection in the U.S. led to integration of the same model within the World Trade Organization (WTO) for biotechnology inventions.

The appropriability of intellectual patent rights measures the effectiveness of the protection from potential technological piracy. If creators of new technology are unable to assert earned property rights over new innovations, it would reduce the incentive for private investment. However, there have been numerous cases where patent protection cases did not hold up in court. Kalaitzandonakes and Hayenga (2000) provide four examples of patent protection failure:

- "In February 1998, Mycogen lost a patent infringement suit against Monsanto, Dekalb, and Delta and Pineland. A jury decided that Mycogen did not prove that it was the first to invent BT technology and considered the patent invalid."
- "Monsanto sought damages and injunctive relief against Mycogen and Novartis for infringement of BT insect resistant patent. A jury verdict in June 1998

found that while the patent was literally infringed by the defendants the patent was not enforceable. Thus, the use of BT genes by Mycogen and Novartis could continue in competition with Monsanto's licensed product."

- "Novartis lost a patent infringement lawsuit it had filed against Monsanto Company and co-defendant Dekalb, over a patent for genetically engineered corn. In November 1998, a jury decided Monsanto and Dekalb did not infringe the patent held by Novartis since January 1997, and that the Novartis patent was invalid."

- "In 1997, Monsanto commercially introduced corn containing a gene from Dekalb providing glyphosate resistance. Rhone Poulenc Agro filed suit against Monsanto and Dekalb contending that they did not have the right to license, make or sell corn products using Rhone Poulenc Agro's technology for glyphosate resistance. Dekalb had sublicensed to Monsanto, glyphosate tolerant technology previously licensed from Rhone Poulenc Agro."

The outcome of cases like these represents the lack of definitive intellectual property rights among GM trait developers. This considerably weakens the ability of firms to capture the full profits from new innovations and reduces the incentive for future investments.

Real Options

Introduction

Trigeorgis and Mason (1987) contend that the "basic inadequacy of the net-present-value (NPV) or discounted-cash-flow (DCF) approaches to capital budgeting is that they ignore, or cannot properly capture, management's ability to reverse its original operating strategy if and when uncertainty is resolved." The ability of managers to make decisions in the future can improve upside potential and limit downside risk.

Alternative approaches, such as simulation and decision tree analysis, have been suggested to alleviate the shortcomings of DCF and NPV. However, these approaches use a constant risk adjusted discount rate, which is only appropriate when uncertainty is resolved continuously at a constant rate of time. Most investment decisions are of a contingent nature in which investments are made in follow-up-stages.

These shortcomings can be properly accounted for by thinking of investment opportunities as bundles of "options" on real assets. An option is the right to buy or sell the underlying asset at a specified price on or before a specified date. The real options approach uses the conceptual framework provided by options pricing theory and applies it to real assets. The common element of using options pricing theory is that the future is uncertain, and having the flexibility to decide when some uncertainty has been resolved has some value. Options pricing theory provides the means to assess that value (Merton, 1990).

Real Options and Research and Development

In contrast to real assets and real commodity options, it is difficult to accurately predict discoveries or estimate future unit sales of research and development products, and there is no established forward unit price market (Paxson, 2001). High uncertainty and intense industry competition force the use of real options analysis to evaluate risks and aide in selecting appropriate research and development projects.

The basic idea of real options on research and development is to transfer the sophisticated option pricing models used in capital market theory to the valuation of risky research and development. However, specific problems are associated with valuing research and development options. Paxson (2001) suggests seven problems:

- Identifying the stages of research and development flexibility and action.
- Modeling the duration, dimension, and diffusion process of the eventual payoff.
- Dealing with the uncertainty in the research and development budget.
- Identifying the time varying volatilities of the process and the underlying values.

- Incorporating the probability of success or failure into the model.
- Assuming the eventual product or process will be perpetuity, without preemption or competition.
- Locating data on research and development that is rarely available to the public.

Despite these problems, the high volatility of the value of research and development outputs positively influences the value of the option because high returns can be generated and extremely low returns can be avoided by reacting to changing conditions. Numerous studies have applied real options to research and development in general, and in specific applications.

Jensen and Warren (2001) applied the use of real options theory to value research and development in the service sector. They contend that research in the service sector is quite different than research in the manufacturing and biotechnology sector. Thus, a different nomenclature should be used in the analysis.

Jensen and Warren analyze the life cycle of an e-commerce project and its different stages of development. The first stage is the research phase, where the firm incurs costs for research and market development. The second stage is the development phase, which is characterized by additional expenditures in market development. The last stage is the implementation phase, which includes commitment to ongoing expenditure during the life of the project.

The real options methodology used to solve the life cycle problem is the compound call option where the research phase buys one option to launch the development phase which, in turn, buys the option to advance to the implementation phase. The authors refer to the Geske Model (1977, 1979) and the Perlitz interpretation (1999) to solve the compound option problem, both of which are discussed further in chapter 3.

The model results in option values that are in the money, where the value of the expected cash flows exceeds the cost of the three-stage development process. The authors note the value of uncertainty in their model. Volatility for the typical e-commerce project is 100%; however, when they solve the problem in terms of a large diversified firm with less volatility, the option value decreases significantly.

Seppa and Laamanan (2001) use real options analysis to value venture capital investments. They derive the risk return profile of stages of venture capital investments in information technology and biotechnology research and development enterprises. There are three major options inherent in venture capital investments: the option to abandon investment, the option to re-value a project, and the option to increase capital commitment.

Seppa and Laamanan test the binomial option-based valuation model with a large sample of venture capital investments. The authors find empirical evidence that their model is consistent with previous knowledge on the risk-return profile of venture capital investments. In addition, they find that their model has predictive power for actual future valuations.

Cortazar, Schwartz, and Casassus (2001) test the optimal exploration investments under price uncertainty and geological-technical uncertainty. They consider several real options, from natural resource exploration to development to eventually mine operation. The problem has two sources of risk: price and geological-technical uncertainty. The price risk is based on the market price of the underlying commodity, and the geological technical risk is based on the size of the discovery.

Cortazar, Schwartz, and Casassus (2001) use the approach of combining both sources of risk into a one-factor model. They hypothesize that this will keep the model structure simple. The model is solved using finite-difference numerical methods which solve the Black-Scholes partial differential equation by approximating the partial derivatives.

The results show that the total project value is due to the options available to the manager at each stage in the process. The value of the project without options (when the value of the expected deposit is 500 units) is -11.44. Then, Cortazar, Schwartz, and Casassus (2001) derive values for three options: the operational option is valued at 6.68; the development option is valued at 2.94; and the exploration option is valued at 3.19. The sum of all values gives the research and development project a total value of 11.37. In addition, when the value of the expected deposits increases, the value of all three options decreases because there is less value in changing the course of action.

Real Options in Agbiotechnology

Little research has been done using real options to value the agbiotechnology development process. However, real options have been applied to other areas concerning GM foods. Primarily, studies have been conducted on the adoption of GM traits from the viewpoint of a state or country. There have also been studies on using compounding options to model changes in the food business (Briggeman, Detre, and Gray, 2005). In addition, research has been conducted on the valuation of international patent rights for agbiotechnology using real options (Nadolnayak and Sheldon, 2002).

Furton, Grey, and Holtzman (2003) analyze the optimal time to license an agbiotechnology product, specifically GM wheat, in Canada. They contend that the adoption of GM wheat is irreversible and extends two primary externalities. First, the spread of the new variety into non-GM crop fields imposes additional costs to non-adopters. Second, there is a potential loss in aggregate market returns due to the lack of effective trait segregation.

The model extends previous research from McDonald and Seigel (1986) into the value of an option to invest in an irreversible project under uncertainty. In the case of GM wheat, the real options value is the social desirability due to externalities and the impossibility of reversing the decision to adopt. The model examines the timing of the license decision for GM wheat.

Calculating the value obtained from the ability to postpone an irreversible investment is similar to the value obtained from holding a call option in the financial markets. The decision maker holds the option to invest now or postpone to a later date. If the value of the option increases, in this case GM wheat becomes more socially desirable, the decision maker has the ability to exercise the option. If the value of the option declines, the decision maker can leave the option unexercised. Deciding to exercise the investment eliminates the value option to wait for more information.

In real options terminology, the option to license a novel product can be characterized as a *timing option*. Timing options occur when the decision maker has the option to delay the investment. The time delay has value because the decision maker is able to wait in hopes of resolving some of the uncertainty associated with the investment. In the case of the release of GM wheat, the time to delay has value because the costs (i.e. negative externalities) have the potential to be reduced.

Furton, Grey, and Holtzman provide results with no segregation and results with segregation. They assume that the more feasible results are with no segregation. If regulators recognize irreversibility and uncertainty, there is value in waiting to license; however, if those two factors are left out of the model, regulators should license GM wheat. The result from the model with segregation (which eliminates externalities) still has value in waiting to license because of the effect of irreversibility.

Carter, Berwald, and Loyns (2004) did a similar study on the release of GM wheat in Canada. The real options model is identical to Fulton et al.; however, there are three key differences: (1) there is disagreement on the price of GM wheat in the market; (2) Carter, Berwald, and Loyns take the view that GM wheat can be segregated; (3) and there are numerous differences in model specifications. Carter et al. suggest that the market will respond to the release of GM wheat as it has with the release of other GM traits, by placing a \$0.15/bushel premium on non-GM wheat. Alternatively, Furton et al. suggest GM wheat will trade at a \$0.20/bushel discount on the world market.

The ability of the grain handling system to segregate GM and non-GM commodities has aided in the success of GM corn and soybeans. Therefore, Carter et al. assume segregation and identity preservation is possible for GM and non-GM wheat at a cost of \$0.15/bushel. In the Furton, Grey, and Holtzman model where segregation is possible, the timing option value is 2.80, which is well above the option value of 2.18 when they assume no-segregation.

The two studies have different opinions on two critical model specifications. The Carter study assumes a 9% increase in yield compared with a 6% increase in the Furton study. Additionally, Carter, Berwald, and Loyns assume a technology-use-fee of \$7/acre, while Furton, Grey, and Holtzman assume a technology-use-fee of $4/acre in their model that allows segregation and $10/acre with no segregation.

These differences in assumptions and model parameters lead to different outcomes. Carter et al. find that the estimated benefits of releasing GM wheat are high enough relative to the costs that the option value is well above the real options threshold. The calculated timing option value of 4.05 exceeds the threshold value of 2.27; therefore, the option to release GM wheat should be exercised.

Summary

Private sector research and development of GM traits has now surpassed the public sector. Investment by the public sector has fallen from 111% of private sector spending in 1960 to 75% in 1996. Decisions about research and development in a competitive environment are different from investment decisions made in the public arena. Firms must adequately account for economic return before beginning the development of a new trait by analyzing the risk and return profile.

Trigeorgis and Mason, among others, contend that current valuation methods are inadequate in capital budgeting because they do not properly capture management's ability to proceed, abandon, or defer an investment. These shortcomings can be accounted for by thinking of investment opportunities as a bundle of "options" on real assets. The real options approach uses the conceptual framework provided by options pricing theory and applies it to real assets.

Real options analysis has been used extensively in valuing research and development projects; however, little has been done specifically on the development of a GM trait. Furton, Grey, and Holtzman used the real options approach to find the optimal time to license a GM trait. However, the option value is characterized by social costs and benefits, instead of the costs and benefits for the private firm.

CHAPTER 3
THEORETICAL MODEL

Introduction

The value of new technologies whose future returns are uncertain present a greater challenge requiring a combination of quantitative and analytical tools. Slight miscalculations can result in underinvestment in possible growth areas, or overinvestment in stagnant ventures with declining or limited possibilities. Thus, valuation methodology impacts both financial and strategic long-run decisions.

Valuation tools are numerous, ranging from the simple (net present value) to the complex (real options). Deciding which tools to use, and in which situation to use them, becomes imperative for decision makers. Typically, situations call for multiple tools used in coincidence or separately to analyze various strategic opportunities.

The real options approach to evaluating investments captures the vast opportunities created by employing resources to uncertain ventures. In the development of new GM traits, firms must be concise in the decisions made at each phase in the development process because of the time (eight to ten years) and financial ($50 to $100 million) commitment made before receiving any revenue.

This chapter presents the foundation and framework of real options. The first section is a review of traditional valuation methods, including the neoclassical view of investment, the discounted-cash-flow (DCF), and the decision tree framework. A detailed analysis of financial options is presented in the second section. The chapter concludes with a deliberate presentation of real options to allow for empirical analysis in the next chapter.

Traditional Valuation Methods

The basis of economic analysis is the efficient and equitable distribution of scarce resources. This responsibility is thrust upon firms on an unremitting basis. Therefore, it is appropriate to review the basic foundations of analysis before delving into the more complex. This section reviews valuation from a neoclassical viewpoint by introducing two common variants of marginal analysis: the user cost of capital and Tobin's q. There is also a review of DCF and the decision tree framework, both of which play an important role in the empirical analysis of this research.

The Neoclassical View of Value

Neoclassical models of investment use marginal valuation methodology. Traditionally, a firm should invest up to the point at which the marginal cost of capital just equals the marginal return to capital. Neoclassical models typically equate investment with the purchase of new equipment or production in an extra unit of a good. Marginal economic theory has two popular variants used in investment analysis: (1) user cost of capital, and (2) Tobin's q.

The user cost of capital, defined by Jorgenson (1963) as the rental rate of capital, derives its value from the purchase price, opportunity cost of funds, depreciation rates, and taxes. A firm's desired capital stocks are determined by the equality of the value of marginal product and the user cost of capital (Hubbard, 1994). Based primarily on the neoclassical model of capital accumulation, the short-run investment behavior of a firm depends on "the time form of lagged response to changes in the demand for capital" (Hall and Jorgenson, 1967).

The desired amount of capital stock K^* is defined as a Cobb-Douglas production function with elasticity of output, represented as γ. Thus,

$$K^* = \lambda \frac{pQ}{c}$$

In this case Q represents the quantity of the output, p and c is the relationship between K_t^* and K_{t-1}^* which implies that each period new projects are initiated until the firm reaches its desired level of capital stock. Therefore, firms invest in new projects when

$$I_t^E = w(L)\left[K_t^* - K_{t-1}^* \neq 0\right],$$

where w(L) is a power series in the lag operator.

The second variant of the neoclassical investment model is Tobin's q, which compares the replacement cost of marginal investment to its capitalized value (Hubbard, 1994). It is represented mathematically as the ratio of m and p, where m is the market value of an asset and p is the asset value. The ratio derives its value from numerous variables, including the return on capital and money, marginal efficiency of capital, income, wealth, and the price of currently produced goods. The investment decision is based upon specific criteria of the value of m / p or, more simply, q. Ranked as:

$q > 1$, Firm should invest

$q < 1$, Firm should not invest and should reduce capital stock

$q = 1$, Firm is at equilibrium capital stock

The model implies that in the long run, q should fluctuate around one as firms adjust investment to reach their equilibrium capital stock.

The user cost of capital and Tobin's q rely on using the net present value (NPV) rule when deciding when to take on a specific investment. They also make two key assumptions: (1) that investments made are largely reversible or have active secondary markets; and (2) that each investment opportunity is an all or nothing situation such that a refusal to invest in a current project eliminates that project for future investment.

Discounted-Cash-Flow

In business operations, firms normally receive cash flows at disparate points in time; therefore, analysis must adjust cash flows to make them equivalent. The time value of money is a basic, yet essential, part of DCF. In order to put cash flows originated at different times on an equal basis, firms must apply an interest rate to each of the flows so they are expressed in terms of the same point in time. The two most common DCF models are net present value (NPV) and internal rate of return (IRR).

The NPV method discounts all cash flows to the present and subtracts the present value of all outflows from the present value of all inflows. In mathematical terms,

$$NPV = \sum_{t=1}^{N} \frac{R_t}{(1+k)^t} - \sum_{t=0}^{N} \frac{O_t}{(1+k)^t},$$

where

t = Time period
n = Last period of project
R_t = Cash inflow in period t
O_t = Cash outflow in period t
k = Discount rate (cost of capital)

The discount rate, k, is often determined by the opportunity cost of capital or, simply put, the cost of capital. If analysis indicates that any given project has a positive NPV, the firm should commence with investment. However, since capital is limited, the firm can rank projects with NPV > 0, and select the project with the greatest value. Conversely, if the NPV of a project has a negative NPV, the firm should not invest. Lastly, when the NPV of a project is exactly equal to zero, the decision is open because the project earns the minimum required rate of return.

IRR takes a slightly different approach to discounting cash flows. Instead of seeking an amount of present value dollars, IRR solves for the interest rate that equates the present value of inflows and outflows. Represented mathematically as,

$$\sum_{t=1}^{n} \frac{R_t}{(1+r)^t} = \sum_{t=0}^{n} \frac{O_t}{(1+r)^t}$$

The r term is the internal rate of return, which is then solved. The internal rate of return is essentially the discount rate that causes NPV to equal zero. In most situations, the recommendations made by IRR and NPV are the same; however, this is not always the case. For example, when the initial costs of two proposals differ or cash flows are received in different income streams, NPV and IRR will provide conflicting decisions.

One of the many weak points of DCF is the methods of accounting for risk in the analysis. Typically, risk is accounted for by using a risk adjusted discount rate (RADR) or a certainty-equivalence. RADR is the most frequently used risk adjustment method (Keat and Young, 2003). RADR assumes that the discount rate, k, is the sum of the risk-free rate, r_f (pure time value of money) and a risk premium (RP). However, the methods for acquiring the appropriate risk premium are not exact and are left to the judgment of the decision maker.

The use of certainty equivalence is another commonly used method of risk adjustment; however, there are at least as many shortcomings in this method as in RADR. The certainty equivalence works through the numerator of the discounting equation by applying a factor to the cash flow to convert a risky cash flow to a less risky one (Keat and Young, 2003). As with RADR, the equivalence factor is left to the judgment of the decision maker, who in some cases may be biased toward certain projects. This reduces the objectivity of using a certainty equivalence or RADR.

The Decision Tree Framework

A decision tree is a visual representation that can help identify all relevant cash flows and their probabilities, thereby enhancing the accuracy and relevance of decisions (Emery and Finnerty, 1997). Decision trees essentially add subjective probabilities to traditional DCF analysis. Decision trees are commonly framed graphically as shown in Figure 3.1. In this example, a firm is confronted with a decision to either invest in the production of a new good or to pass. At the end of the tree, β and α represent the respective payoffs of either fast or slow adoption of the new product, and p is the probability of fast adoption.

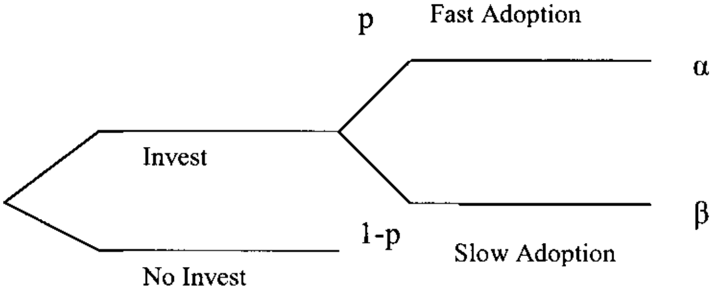

Figure 3.1. Traditional Decision Tree.

Typically, the payoffs of decision trees are either the expected monetary payoff, utility received from the investment and subsequent adoption, or the NPV of cash flows. Decision trees are most easily solved using backward induction, from end to beginning, starting with each final outcome. So, if $(p \times \alpha) > ((1-p) \times \beta)$ the firm should invest in new product development, if not, the firm should not invest.

Traditional valuation methods are useful, but incomplete. Many investments incur numerous stages of development, which provides multiple and continuous decisions and subsequent managerial flexibility. Traditional methods alone cannot capture the value of such flexibility or the value associated with the contingent nature of the development process. However, used alongside the options theory, traditional methods can provide more accurate insight into strategic and investment decisions.

Options and Option Pricing

The first organized options exchange was developed by the Chicago Board of Trade with the intent of trading stock options. In subsequent years, the American, Philadelphia, and Pacific Stock Exchanges began trading options. As markets developed, options on new instruments, such as currency, futures, and indices, became available (Hull, 2005). In addition to exchanges, traders can buy or sell options in the over-the-counter-market, which offers more tailored securities to fit specific needs.

According to Hull (2005), there are three types of traders: hedgers, speculators, and Arbitrageurs. Each type of trader contributes significantly to the success of options markets, mostly by providing liquidity. Hedgers use options to reduce risk associated with some market variable they or their firm may be exposed to. Speculators use options as a leverage mechanism to make large bets on the direction of market variables. Lastly, Arbitrageurs take offsetting positions in multiple instruments to receive a costless and risk-free profit.

Types of Options and Payoffs

There are two basic types of options: call and put. The call option gives its owner the right to buy the underlying asset at a specified price on or before a given date. If, at expiration, the value of the underlying asset is less than the strike price, the option is considered "out of the money" and not exercised. However, if the value of the underlying asset is greater than the strike price, the option is considered "in the money" and should be exercised (Bodie, Kane and Marcus, 2004). The profit to the buyer of the option (long position) is $MAX(S_t - K - \omega, 0)$ where S_t is the value of the underlying asset, K is the strike price, and ω is the option premium. Figure 3.2 illustrates the profit to the holder of a call option.

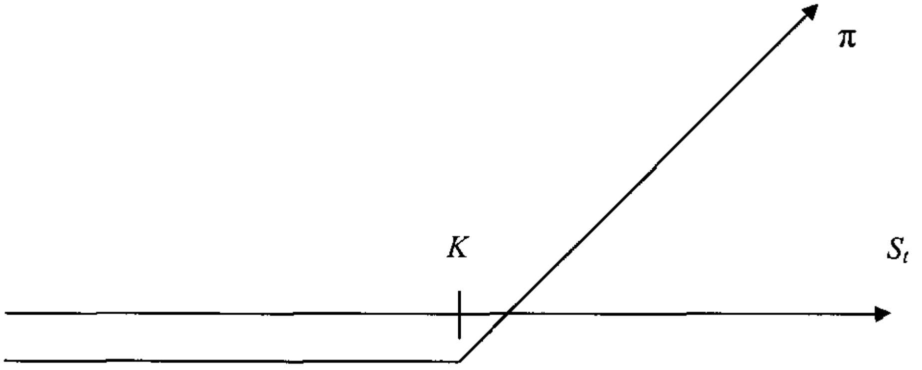

Figure 3.2. Profit for a Long Position on a Call Option.
Source: Damodaran (2005).

For every long position in an options contract, there must also be a short position. The writer of a call option assumes the short position of each call option. According to Hull (2005), the writer of a call option receives cash upfront or the options premium but incurs potential liability later. The writer's profit is the reverse of the buyer; thus, $MIN(K + \omega - S_t, 0)$ where the writer of the call option is anticipating the value of the underlying asset to be flat or negative.

A put option gives the buyer of the option the right to sell the underlying asset at a fixed price either on or before the expiration date. If the price of the underlying asset is greater than the strike price, the option is out of the money and will not be exercised.

However, if the price of the underlying asset is less than the strike price, the put option is in the money and should be exercised. The profit of the buyer of a put option is $MAX = (K - \omega - S_t, 0)$. Figure 3.3 illustrated the profit of for the holder of a put option.

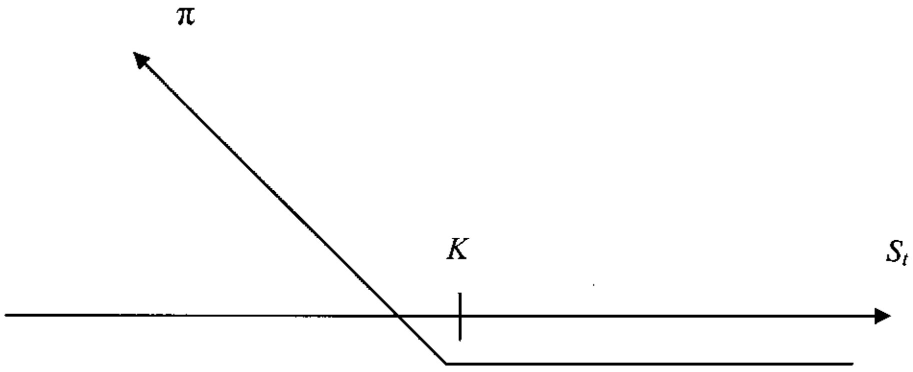

Figure 3.3. Profit for a Long Position on a Put Option.
Source: Damodaran (2005).

The writer of a put option is anticipating either a flat market or an increase in the value of the underlying asset. As with the call option, the writer of a put option receives cash upfront in the form of the option premium. The profits for writing a put option can be represented mathematically as, $MIN(S_t - K + \omega, 0)$.

The writer of an option contract is exposed to substantial loss. The writer of a call option could, theoretically, incur an infinite loss (there is no ceiling to the price of an underlying asset). However, the buyer of an option contract's loss is capped at 100% because if the market goes in the opposite direction the option is not exercised, and the loss is the premium paid to enter the contract.

Although American and European calls and puts are the most common types of options contracts, there are many others commonly referred to as "exotic" options. These new products have been driven primarily by the demand for customized options, which provide various benefits not found in traditional contracts. For example, Asian options depend on the average price of the underlying asset, as opposed to the final price. There are also barrier options where the payoffs depend on some asset price and on whether the underlying asset crosses some previously agreed upon barrier. Another exotic option is the lookback option whose payoff depends in part on the minimum and maximum price of the underlying asset during the life of the contract (Bodie, Kane and Marcus, 2004).

Option Pricing

Determinants of Option Value.

Six primary variables affect the value of an option. First, the value of the underlying asset affects both call and put options, but in different ways. For call options, an increase in the value of the underlying asset leads to an increase in the value of the option. Conversely, an increase in the value of the underlying asset will have a negative effect on the value of a put option (Damodaran, 2005).

The second determinant of the value of an option is the variance in the price of the underlying asset. The higher the variance in the value of an option, the greater the option value. Although counterintuitive, higher volatility means there is a greater chance of the value at expiration being either very high or low. Since the maximum loss is the option premium, the potential gain from uncertainty overshadows the potential loss. This is true for both call and put options (Hull, 2005).

Dividends paid on the underlying asset also affect the value of an option contract. For example, if a company prepares to make a dividend payout, it has less cash to reinvest in the business, causing a decrease in the price of the stock. That being the case, a dividend payout has a negative effect on a call option and a positive effect on the value of a put option.

The strike price and the risk-free interest rate also determine the value of an option. The more the strike price increases, the lower the value of a call option and the higher the value of a put option. Conversely, the lower the strike price, the greater the value of the call option and the lower the value of the put. Lastly, the risk-free interest rate represents the opportunity cost of funds paid for the options premium.

Put and Call Parity. Put and call parity can be deduced from the arbitrage opportunities that are available to investors. According to Stoll (1969), the best way to analyze this relationship is through the cash flows associated with two portfolios. Initially, the investor writes a call option yielding the positive cash flow *(C)*, and the purchase of a put *(P)* results in a negative cash flow.

To go long, the investor must borrow V at the risk-free rate *(i)* for the length specified on the option contract. The interest cost can be represented mathematically:

$$\frac{V \times i}{(1+i)}$$

The following equation summarizes the previously mentioned cash flows:

$$C - \frac{(V \times i)}{(1+i)} - P = M\ ,$$

where M represents the profits from the arbitrage opportunity. The same sequence can occur for the put option; following the above equation, the put option can be represented as,

$$P + \frac{(V \times i)}{(1+i)} - C = N\ ,$$

where N represents the profits from the above arbitrage opportunity. According to Stoll, in a perfect world with no transaction costs, M and N should be equivalent. The difference in the put and call price is equal to the present value of borrowing at the risk-free rate of interest. Therefore,

$$c - p = \frac{i}{(1+i)} = i$$

Black-Scholes Model. Initially, the Black-Scholes model was designed to value European call options with no dividend payments. Therefore, early exercise and dividend payouts have no affect on the value of the call option. According to Damodaran (2005), the value of a call option can be written as a function of the following variables:

S = Current value of the underlying asset
K = Strike price of the option
T = Life to expiration of the option
R = The risk-free rate corresponding to the life of the option
σ^2 = Variance in the LN(value) of the underlying asset

The model itself is written as

$$V = SN(d_1) - Ke^{-rt}N(d_2),$$

where

$$d_1 = \frac{\ln\left(\frac{S}{K}\right) + \left(r + \frac{\sigma^2}{2}\right)t}{\sigma\sqrt{t}}$$

$$d_2 = d_1 - \sigma\sqrt{t}$$

The determinants in the value of the Black-Scholes include the following: current value of the stock price, variability in the stock price, time to expiration on the option, the strike price, and the risk-free rate of interest (Damodaran, 2005). Implicit in the Black-Scholes model is the replicating portfolio. Black-Scholes constructed a portfolio of traded securities, known as a tracking portfolio, to have the same payoff as an option (Amram and Kulatilaka, 1999). By the law of one price, two assets with the same payoffs must have the same current value. This ensures that no arbitrage opportunities exist in the valuing of an option.

Binomial Pricing Model

Cox, Ross, and Rubenstein first introduced the Binomial Options Pricing method in their 1979 paper titled *Option Pricing: A Simplified Approach* (Cox, Ross, and Rubenstein, 1979). The binomial option pricing model is often represented in a decision tree that follows different possible price paths by the stock price over the life of the option (Hull, 2005). The essential technique in pricing options is to create a package of investments in the stock and loan that will exactly replicate the payoffs from the option.

Hull (2005) explains Figure 3.4 as a sequence of steps. First, consider a stock whose current price is S_0 and an option on the same stock whose current price is represented as f. The stock can either move up to S_0u or down to S_0d in time T. The proportion of upward movement is u-1, and the proportion of downward movement is 1-d. If the price of the stock moves up, the payoff for the option is f_u; if the price of the stock moves down, the payoff of the option is f_d.

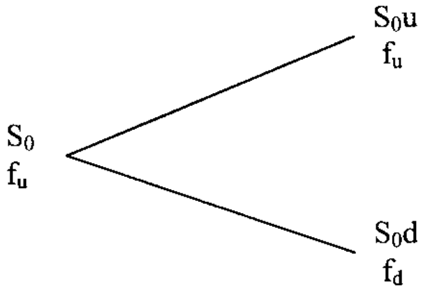

Figure 3.4. Stock Price Movements Represented in a One Step Decision Tree.
Source: Hull (2005).

Assume there is a long position in the underlying shares of stock, and a short position in one options contract. There is an upward movement in the stock price

$$S_0 u\Delta - f_u$$

or a downward movement

$$S_0 d\Delta - f_d$$

This creates a riskless portfolio and must earn the risk-free rate of interest. The present value of the portfolio is

$$(S_0 u\Delta - f_u)e^{-rt}$$

The cost of setting up the portfolio is $S_0\Delta - f$; therefore, $f = S_0\Delta(1 - ue^{-rt}) + f_u e - rt$.

Substituting for delta and simplifying:

$$f = e^{-rt}\left[pf_u + (1-p)f_d\right], \tag{3.1}$$

where

$$p = \frac{e^{rt} - d}{u - d} \tag{3.2}$$

Equations 3.1 and 3.2 enable an option to be priced using a one-step binomial pricing model, by solving equation 3.2 and replacing its solution with p in equation 3.1.

The binomial tree analysis can be extended to multiple steps. The objective is to solve the option price at the initial node of the tree, which is done by repeatedly applying the principles established above (Hull, 2005, p.249). The length of time T is now replaced with Δt years in the previous equations to account for the multiple steps in the binomial pricing method.

$$f = e^{-r\Delta}[pf_u + (1-p)f_d] \tag{3.3}$$

$$p = \frac{e^{r\Delta t} - d}{u - d} \tag{3.4}$$

Then, depending on how many steps are in the model, equation 3.3 is repeated. The following sequence of equations represents a multi-step binomial model

$$f = e^{-r\Delta}[pf_{uu} + (1-p)f_{ud}] \tag{3.5}$$

$$f = e^{-r\Delta}[pf_{ud} + (1-p)f_{dd}] \tag{3.6}$$

$$f = e^{-r\Delta}[pf_{u} + (1-p)f_{d}] \tag{3.7}$$

Substituting from equations 3.5 and 3.6 into 3.7, we get

$$f = e^{-2r\Delta t}[p^2 f_{uu} + 2p(1-p)f_{ud} + (1-p)^2 f_{dd} \tag{3.8}$$

The variables p^2, $2p(1-p)$, and $(1-p)^2$ are the probabilities that the upper, middle, and lower nodes will be reached. The option price is equal to its expected payoff in a risk-neutral world discounted to the risk-free rate of interest (Hull, 2005, p.251).

Risk-Neutral Valuation

The Black-Scholes model does not depend on a discount rate or other variables that are affected by the risk preferences of investors. The variables presented in the formula – current stock price, time, volatility, and the risk-free rate of interest – are all independent of risk preferences. This is the most critical component of options and other derivatives, risk neutral valuation.

Risk neutral valuation assumes all investors are risk-neutral and do not need additional compensation for taking on risks. In this risk neutral world, the expected return from the underlying asset is equal to the risk-free interest rate, and the discount rate to discount the expected payoff is risk-free interest (Hull, 2005, p.247). However, the solutions obtained in a risk-neutral world are valid in all worlds.

To illustrate risk-neutral valuation, consider the simple one-step binomial structure in Figure 3.1. The expected stock price will be given as $E(S_t)$ and represented as

$E(S_t) = pS_0u + (1-p)S_0d$

Substituting from equation 3.2 for p, we obtain

$E(S_t) = S_0e^{rT}$

The expected growth rate of the stock is the risk-free rate. Setting the probability of the up movement equal to p_u is to assume that the expected return on the stock is the risk-free rate. In the risk-neutral world, individuals are expected to maximize value and require no additional compensation for risk, and the expected return for all securities is the risk-free rate. The risk neutral valuation principle states that it is valid to assume the world is risk neutral when pricing options. The result is correct for all worlds, not only in the risk-neutral world (Hull, 2005, p.247).

Research and Development with Real Options

Investing in research and development can be thought of as investing in future opportunities: real options can be used to value such opportunities (Luehrman, 1997). In real options, the thinking behind financial options is extended to real assets but without imposing any obligation to invest further into a project.

Research and development of a new GM trait lends itself well to the application of the real options framework because the development process is staged, and there are measurable risks and uncertain outcomes to each stage. Like financial options, real options protect the full potential gain of developing a new trait while reducing the potential loss because of the ability to abandon the project at any one of the five development stages.

The following section introduces the most important types of real options. In addition, there will be an overview of real options valuation methodology, which will include the adaptation of the Black-Scholes model to the pricing of a real option.

Types of Real Options

The key to using real options is the ability to identify the correct application for framing a potential decision (Amram and Kulatilaka, 1998); it should be looked at as, "if we begin our path from point A to point B, what options will open up for us and what will we gain."

There are numerous types of real options, but three are of particular interest for analyzing research and development investments. Timing options, typically, occur when the decision maker has the option to delay the investment. The time delay has value because the decision maker is able to wait in hopes of resolving some of the uncertainty associated with the investment.

The abandonment option arises when firms have the option to stop production or research and development on products whose market opportunities have diminished. The abandonment option fits well with the development of a new GM trait. For example, after the discovery stage of development, the new trait enters the proof of concept stage where they attempt to forecast possible demand. If demand and expected revenue are less than the cost to continue development, the firm can abandon production before entering proof of concept. In this case, the option to abandon has value because the firm avoided further investment into the last three stages, thus avoiding extra costs for a commercially doomed product. Abandonment options are akin to a put option on a common stock.

An investment includes a growth option if it allows a follow on investment to be undertaken, and the decision to take the follow on investment will be made later based on new information. Such projects are commonly perceived to have strategic value. Growth options give you the right, not obligation, to receive something for a given price; therefore, they resemble the call option.

Sometimes, when looking at research and development, it is good to look at the time to build option – which includes staging investment as a series of outlays, creating the option to abandon or grow depending on the arrival of new information. Each stage can be looked at as a call option on the previous stage.

Real Option Valuation Methods

The tools developed to value financial options can be useful in valuing real options embedded in most projects. However, since real options are more complicated than financial options, it is imperative to simplify real option analysis to fit financial models. As with all valuation tools, the purpose of real option analysis is to assist in the decision making process, not replace the sound and reasoned managerial functions of a business.

Luehrman presents a simple, yet effective, way of using the Black-Scholes model to value real options (1998). One can map an investment opportunity onto a call option, which uses the same value drivers as the Black-Scholes model. The present value of a project's operating assets to be acquired represents the stock price, the expenditure required to acquire the projects assets represent the exercise price, length of time the decision can be deferred represents the time to expiration, the time value of money represents the risk-free rate of interest, and the level of risk associated with the project assets represent the variance of returns on stock.

Table 3.1 represents a map of investment opportunities onto a call option. The stock price variable represents the present value of assets required. The strike price of a call option is synonymous to the cash outflow to acquire an asset. The time to defer an investment is equal to the expiration date of a call option, while the time value of money relates to the risk-free rate of interest and the stock variance with the riskiness of the project.

Table 3.1. Map of Investment Opportunities onto a Call Option

Investment Opportunity	**Variable**	**Call option**
PV of assets acquired	S	Stock price
Outflow to acquire assets	X	Strike price
Time of deferral	T	Time to expiration
Time value of money	r_f	Risk-free rate
Riskiness of project	σ^2	Variance of returns

Source: Luehrman (1998a)

Luehrman creates an option space, using two metrics, to rank and evaluate real options. The first metric contains the data captured in NPV but adds the time value of being able to defer the investment. Luehrman calculates the NPV_q, which is defined as the value of the underlying asset divided by the present value of the expenditure required to purchase them. In Figure 3.5, NPV_q is referred to as the value-to-cost. When the value-to-cost metric is between zero and one, we have a project worth less than it costs; when the metric is greater than one, the project is worth more than it costs.

The second metric is loosely referred to as volatility. This metric measures how much things can change before the next investment decision must be made. The *volatility* metric is determined by two factors. First, uncertainty of the future value of the asset is captured by the variance per period of asset returns; second, the length of time the investment can be deferred is determined by using the options time to expiration.

Projects are ranked by their location on the option space. If the project has low volatility and a low value-to-cost ratio, it is placed in the "never invest" category, but if the project has low volatility and a high value-to-cost ratio, it placed in the "invest now" category. Rankings are then placed in “maybe now” or “probably later” depending on the level and various combinations of volatility and value-to-cost. Generally, projects with value-to-cost above one are suitable for investment now or have the potential for investment in the future.

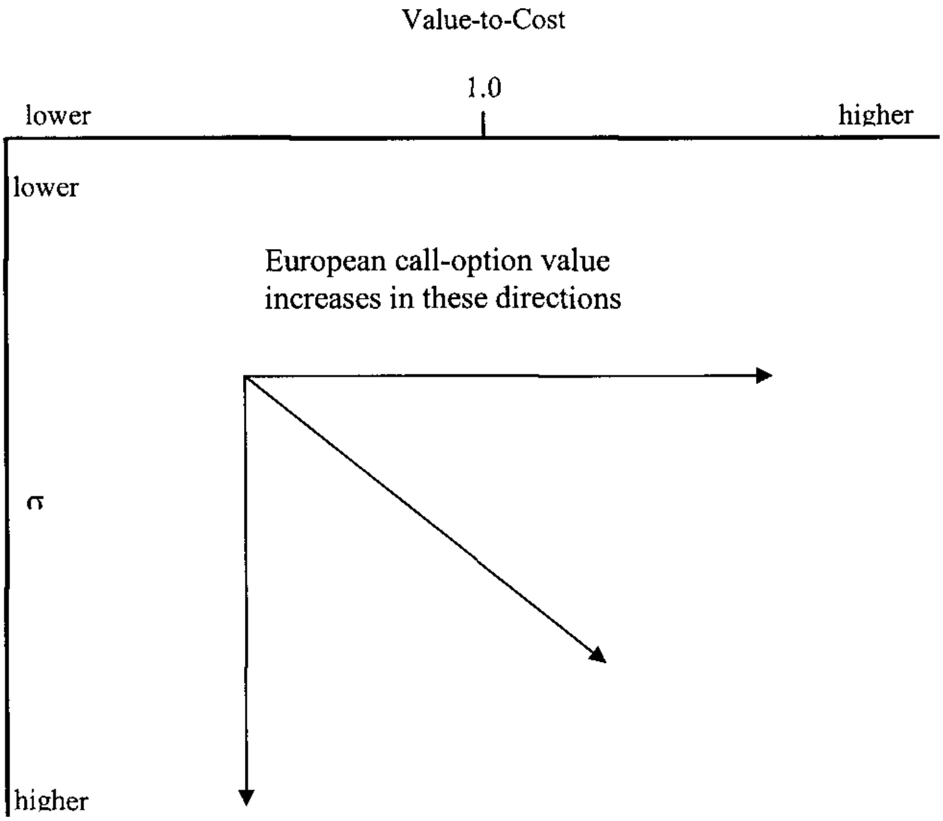

Figure 3.5. Luehrman’s “Option Space” is Defined by Two Option Value Metrics.

Copeland presents a framework that is divided into four steps (Copeland and Antikarov, 2003). Step one requires the determination of a value for a “base case” project that has no flexibility built into it using the standard, discounted cash-flow. Step two explicitly identifies and models the critical uncertainties involved with the project. Step three creates a decision tree that can be analyzed to identify the places where management possesses managerial flexibility. Step four then uses real option valuation techniques, such as the Black-Scholes or binomial model, to determine the value of the option. The option value is then compared to the cost of the option to determine whether to make the investment.

Similarly, Amram and Kulatilaka developed a four-step process for designing and solving real options. The largest source of error made in real options analysis is that the application is poorly framed. Therefore, the first step is to frame the application. The first step includes five critical elements that must be incorporated into developing a good application frame for sound analysis:

- The decision: what are the possible decisions, when might they be made, and who is making them?
- The uncertainty: identify the form of evolution for each source of uncertainty and lay out any cash flow and/or convenience yields.
- The decision rule: create a simple mathematical expression.
- Look to the financial markets: which source of uncertainty are private and which are market priced? Is there an alternate application frame that better uses the financial market for information?
- Review for transparency and simplicity: who would understand this application frame?

The second step is to implement the option valuation model that is tailored for the specifics of the application. The primary component of step two is establishing the inputs to the model by calculating the current value of the underlying asset, cash flows, and volatility for each source of uncertainty and obtain data on the risk-free rate of return.

Once inputs are established, it is time to select an options valuation method and obtain the numerical result.

The third step is to review the results from the options valuation. The valuation results provide several types of results, which include critical values for strategic decision making as well as results that help quantify the investment's risk profile. The fourth step is to redesign if necessary.

Summary and Managerial Implications

Many business investments can be implemented flexibly through deferral, abandonment, expansion, or in a series of contingent investments. The traditional discounted cash flow method when naively applied fails to capture all the future opportunities that create value, thereby resulting in an underinvestment in research and development. The real options approach, which applies financial options theory to real assets, is more appropriate because it views a research and development project as an initial investment that creates future growth opportunities.

There are numerous types of real options, but three are of particular interest for analyzing research and development investments. The timing, abandonment, and growth option relate well to research and development because the development process is staged, and each stage has measurable risks and uncertain outcomes. The use of real options will maximize the value of profitable projects and minimize investment in unprofitable ventures by allowing management to change course as market dynamics shift.

CHAPTER 4
VALUING AGRICULTURAL BIOTECHNOLOGY: THE REAL OPTIONS APPROACH

Introduction

Real options are ideal for valuing projects where managers are flexible enough to adapt to shifts in market dynamics. The ability to profitably respond to new competitors or adverse situations is the basic tenant of this analysis. Development of a new GM trait is rife with both endogenous and exogenous risk. Early in the development process, the firm faces significant technical risk, where various milestones are required to move to the next stage. Toward the end of the process, the firm faces exogenous risk in the form of political and market uncertainty. The real options approach will account for these sources of risk through risk neutral analysis.

Chapter 3 outlined the framework and application of real options. The development of a GM trait is considered a growth option where technical or marketing milestones must be completed before management can exercise the option to invest further in the project. This chapter presents a simulation methodology model for valuing real options on trait development projects. The first section outlines the model framework and objectives. The next section identifies data sources and distributions. Third is a brief discussion on stochastic simulation procedures using Palisades @Risk. The last section provides a look forward to sensitivities on key random variables in the results chapter.

Real Options Model Overview

The real options model is used for creating a standardized method for valuing GM trait development. The process can be modeled using several different types of real options. For example, the option to abandon could be used because the development firm can abandon the project at any given point if market conditions shift. Similarly, one could use the time to build option, where staged investments create the option to abandon the project at midstream if new information is unfavorable.

However, in this case the real option is a growth option, which is defined by an early investment that is a prerequisite or linked to follow-on investments and future growth opportunities. In the case of GM trait development, each phase of the process contains specific milestones and has certain technical risk. For example, in the discovery phase, developers must begin with gene efficacy in a model plant system, and succeed, before they can begin trait efficacy in target crop or plant production systems in the proof of concept phase (McElroy, 2004).

The GM trait development process lends itself well to traditional sequential new product development models, where the process is classified along a spectrum that emphasizes cause-and-effect and time relationships of specific activities. In the case of GM traits, there are five phases, each of which is identified with a set of milestones and the probability of success, time, and cost. The growth option provides the trait developer with the internal or external flexibility to participate in future growth options with minimal investment (Jagle, 1999).

GM Traits Analyzed

Furton, Grey, and Holtzman, as well as Carter, Berwald, and Loyns, modeled GM traits as *timing options* to account for the irreversible nature of the technology's release into the market. However, the valuation of the development process and modeling of the optimal time to release the GM trait are of different context. Modeling the risks and costs of developing a new trait is important to the strategy of the firm, but it is not analogous to the *public* decision to license the trait.

The issue of public response to externalities, irreversibility, and licensing are captured in the regulatory phase, where the firm must adequately manage the associated risks and costs before exercising the option to commercialize the trait. Growth option parameters can be adjusted to fit the level of expected or actual scrutiny given to a trait as new information becomes available. For example, traits used for food crops have been more intensely scrutinized than those used in the feed market; therefore, developers can modify the time and cost parameters in the model.

There will be three GM traits analyzed. The following is a summary of trait characteristics, and why the valuation of the trait is suited to a growth option.

<u>BT Corn.</u> Bacillus thuringienisis (BT) is a naturally occurring soil bacterium that produces proteins that selectively kill specific groups of insects (Gianessi, 2002). BT varieties have been available since 1996 and have seen substantial adoption, with the 2007 adoption rate of 25%. The case of BT corn is used in this research because it has already seen commercial success, as opposed to the other traits that are still in experimental phases.

<u>RoundUp Ready Wheat.</u> The RoundUp Ready wheat trait is designed to allow producers to spray wheat with the glyphosate herbicide (RoundUp) without damaging the plant (Gianessi, 2002). The transformed plant contains an additional gene that produces EPSP synthetase that glyphosate does not inhibit, thus protecting it from its application.

Glyphosate is a widely used application in U.S. spring wheat, and to a lesser extent in U.S. winter wheat. In the United States, 30% of planted spring wheat acres and 15% of planted winter wheat acres apply glyphosate for weed control. There is also potential for use in western Canada where similar weed problems exist. It will be assumed that Canadian western red spring wheat use is similar to that of U.S. hard red spring.

RoundUp Ready wheat is not commercially available, but the developer has been conducting field trials since 1994 and has successfully passed the technical hurdles required for development. According to Gianessi (2002), research has shown that applications of RoundUp provided 95% to 99% control of both grass and broadleaf weeds, which are standard reasons for herbicide use. When the herbicide was applied to the RR resistant wheat in field trials, "no injury to the transgenic wheat was observed." However, RR wheat was finally pulled out of the regulatory submission process following two years of work due to consumer resistance, primarily in Japan and Europe.

Fusarium-Resistant Wheat. The FR wheat trait is, theoretically, designed to alleviate the damage caused by the fungal virus Fusarium Head Blight. FR resistant wheat is not yet commercially available, but industry acceptance in the United States has grown favorably. Fusarium disease reduces yields and can produce a toxin that makes the wheat unfit for human consumption. Outbreaks of fusarium tend to occur in high moisture conditions from rain, dew, or humidity and coincide with the flowering stage of plant development. Fusarium head blight in wheat is most prevalent in the HRS region of the United States and the western red spring region of Canada.

The development of FR wheat, as with other GM traits, is well suited to be valued by real options, particularly growth options. In the case of FR wheat, many of the options to move on to the next phase of development have been exercised, particularly the discovery through early development phase. Full commercialization of FR wheat is expected in four to six years but was met with same resistance as the RR wheat trait.

Determining the Growth Option Value

The model is an extension of Jagle (1999), who developed a real options model for a "new product development" case study. The model is applied to BT corn, RoundUp Ready wheat, and Fusarium resistant wheat. The development of a new trait is identified as a growth option because of the characteristics of the development cycle. The development of the analytical model follows a specific set of steps. In the first step, all option drivers are mapped along an option tree. In the second step, calculations are done in order to solve the inner nodes of the option tree through backward induction. In the third step, single period probabilities are converted to risk-neutral probabilities in order to allow risk-neutral valuation. In the last step, backward induction is repeated, but this time using risk-neutral probabilities.

The binomial option tree only considers two outcomes: success or failure. If the phase is deemed successful, development will advance to the following phase; if the phase is deemed a failure, then the growth option is not exercised and the option expires – and is worth only the salvage value. Figure 4.1 summarizes the option tree for the BT corn trait. The lower-level timeline reflects the phase and its base case completion time. The Discovery phase takes three years to complete, while the proof of concept, early development, and advanced development phase takes 18 months, and the regulatory submission phase takes two years. Above the time component, along the options map, is the expected cost for each phase of development. The dollar values at the bottom node represent the base case salvage value if the representative phase is a failure. Along the top of the option tree are the risk-neutral probabilities. The discovery phase has a risk-neutral probability of 17%, which is interpreted as a 17% probability of moving to the proof of concept phase. The risk-neutral probability increases as we move to subsequent stages of development. The values along the lower branches of the tree are the failure probabilities.

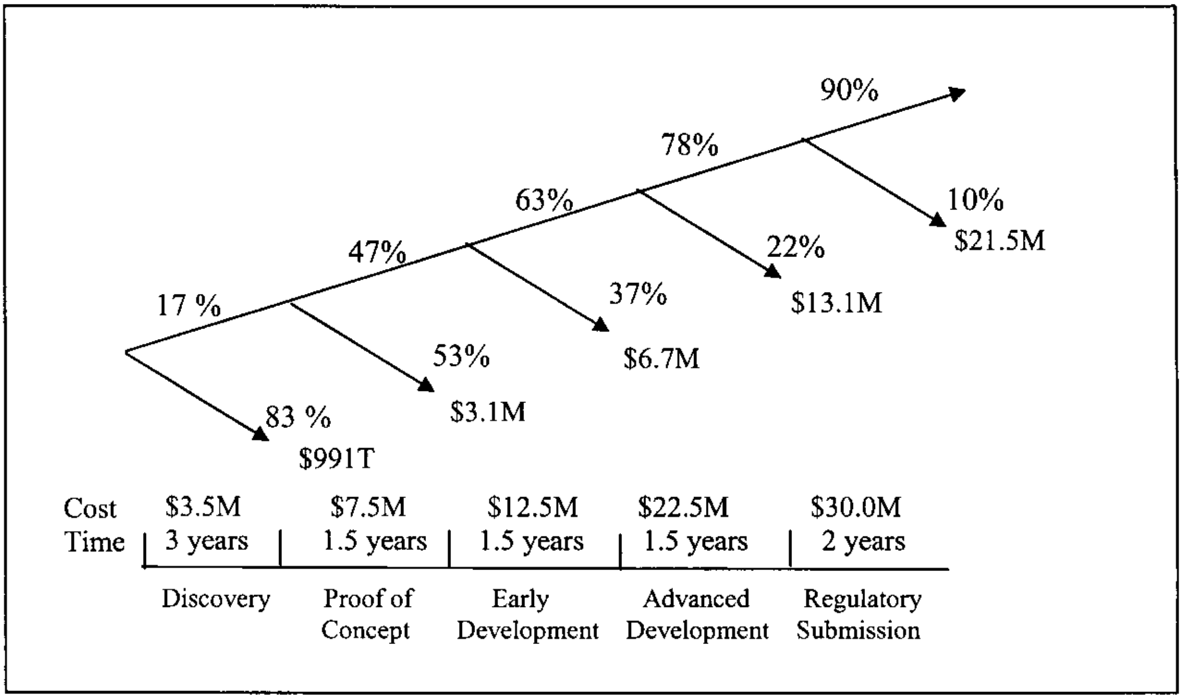

Figure 4.1. Option Tree.

The values of the inner nodes (not shown in the above diagram) are calculated by working backward through the options tree. The most outer-node is the present value of cash flows from the time of commercialization and the end of patent protection for a given GM trait.

The present value of cash flow is determined as follows:

$$PV = (TF * PA * A - RC) * \left(\frac{1}{1+WACC}\right)^{t},$$

where

TF = Technology fee received for the use of the trait
PA = Planted acres for given crop
A = Adoption rate of new trait
RC = Residual costs
t = Time
WACC = Weighted Average Cost of Capital

Following the development of the present value of cash flows, we weight the cash flows at the end of the regulatory submission phase by its respective success and failure probabilities, and then discount the result by the duration of the phase, using an assumed weighted average cost of capital of 10%. This process is continued until all values along the inner nodes of the option tree have an assigned solution.

The single period probabilities are converted into risk-neutral probabilities. Risk neutral probabilities are used in option pricing to allow the use of the risk-free interest rate, as opposed to identifying the risk-adjusted discount rate. According to Jagle, risk-neutral probabilities are the discrete-time equivalent to the method used in continuous time option pricing of creating a risk-neutral "hedge" portfolio. In a risk-neutral portfolio, positions of the option and the underlying asset are combined, so the value of the portfolio is the same as the underlying asset. Therefore the value of the portfolio is not affected by the risk of price changes, and then the risk-free interest rate can be used for discounting its value to the present (Jagle, 1999).

The risk neutral probabilities are solved as follows:

$$\mathrm{p} = \frac{(1+r)^t s - s_-}{(s_+ - s_-)}, \qquad (4.1)$$

where

P = Risk-neutral probability
r = Risk-free interest rate
S = Current project value
S^+ = PV of cash flow at the end of the phase if upward movement
S^- = PV of cash flow at the end of the phase if downward movement
t = Time

Table 4.1 illustrates the single period and risk neutral probabilities derived using equation 4.1.

Table 4.1. Risk Neutral Probabilities

Development Phase	Single Period	Risk Neutral		
	All Traits	Bt Corn	FR Wheat	RR Wheat
Discovery	20%	17%	17%	17%
Proof of Concept	50%	47%	47%	47%
Early Development	67%	63%	62%	60%
Advanced Development	83%	78%	78%	78%
Regulatory Submission	90%	90%	84%	84%

As with the first step, backward induction is used to calculate the option values for the outer nodes, but this time risk neutral probabilities are used. Figure 4.2 presents the option tree with the calculated option values using the risk neutral probabilities. For the firm to exercise the growth option, the value must be greater than zero. In the case below, as uncertainty is resolved the option value increases. It should also be noted that as the firm experiences success, knowledge of the market increases, adding more "learning" value. Additionally, when the firm is, for example, in the advanced development stage, the model is forward looking; therefore, the previous investment costs are now sunk and do not affect the option value or management decision on moving ahead.

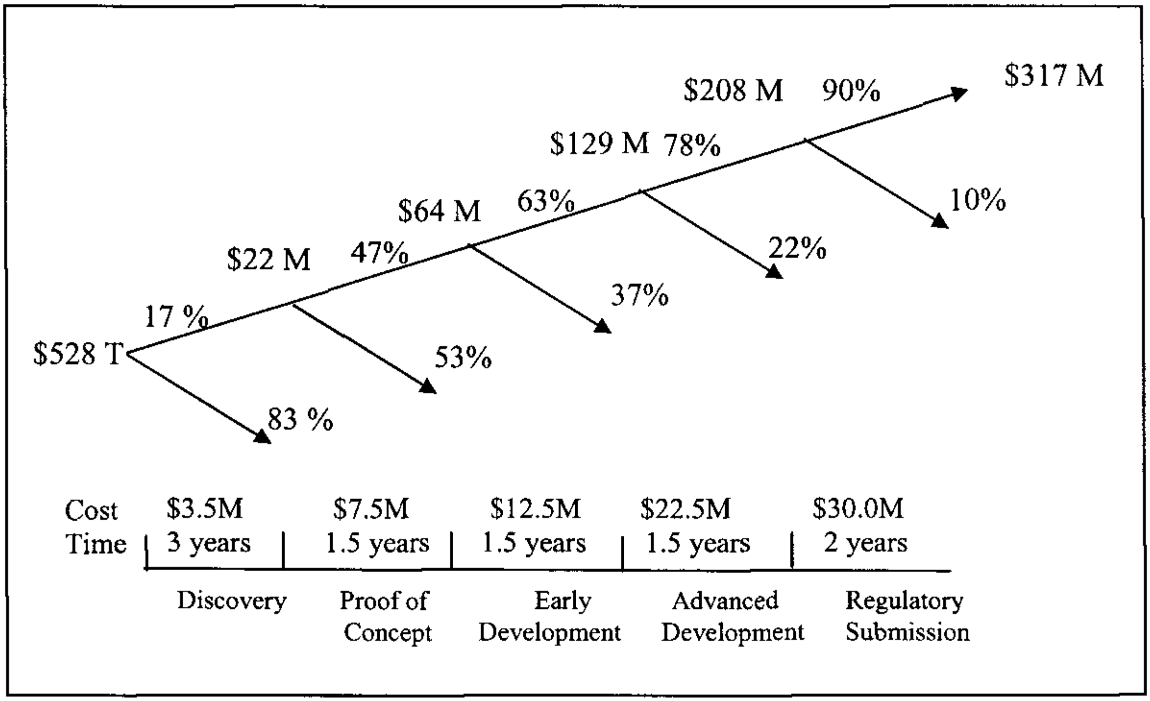

Figure 4.2. Option Tree with Calculated "Real Option" Values for FR wheat.

Base Case

The base case, presented in Table 4.2, is the most likely scenario, which sets the mean parameters for later sensitivity analysis. The base case model contains numerous random variables that determine the value of the growth option. On the revenue side of the model is the adoption rate and the technology-use-fee. The adoption rate, which is an assumption of producer demand and demand growth over the life of the patent, follows the general new technology adoption cycle put forth by Boer (2004). The base case technology-use-fee for BT corn is the current market price per acre, while the values for FR and RR wheat are analytical results from Huso (2005).

Table 4.2 Base Case Random Variables

Random Variables	**Base Case**	**Logic**
Adoption Rate (% per year)	10,15,25,35,45,30,30 and 30	Adoption follows the traditional new product development cycle
Salvage Value	35% of investment	Research and internal value even if not released commercially
Time		
Discovery	3.0 years	
Proof of Concept	1.5 years	All mean development time values are
Early Development	1.5 years	sourced from Monsanto estimates
Advanced Development	1.5 years	
Regulatory Submission	2.0 years	
Technology Fee ($/acre)		
Bt Corn	$7.40	Market price
FR Wheat	$12.40	Estimate from Huso
RR Wheat	$5.10	Estimate from Huso

Additionally, base case variables for the time it takes to complete each stage of development are included. Because each stage has a different set of milestones, the time it takes to complete them varies. Lastly, the salvage value represents the value received if the project does not move on to the next development stage. In this thesis, the base case salvage value is assumed to be 35% of the investment made in the project.

Data Sources and Distributions

Data were collected for the potential market size for each GM trait; BT corn was limited to all planted corn acres in the United States; while RR wheat and FR wheat considered hard red spring wheat area of the United States and the western spring wheat region of Canada. Five-year averages for all planted area were obtained from the USDA and the Canadian Grains Commission.

The first element of the revenue model is the technology-use-fee (TUF). The firm decides what value of the TUF based on the availability of competing technologies. The technology use fee, measured in $/acre, for BT corn is $7.4/acre, which is known because the trait has been made commercially available. The technology use fee for RR wheat and FR wheat are estimated at $12.4/acre and $5.1/acre (Huso, 2005), respectively. The adoption rate for GM traits is assumed to follow the new technology adoption cycle put forth by Boer (2002).

The technology adoption cycle, illustrated in Figure 4.3, is based on a four-staged approach. The first stage, or incubation stage, exists between the point of conceptualization and the time of full commercialization. In the second sage, or the rapid growth stage, product sales or product adoption begin to grow rapidly. The mature growth stage is when adoption growth is maintained. Lastly, maturity exists when competing technologies enter the market and adoption begins to decline.

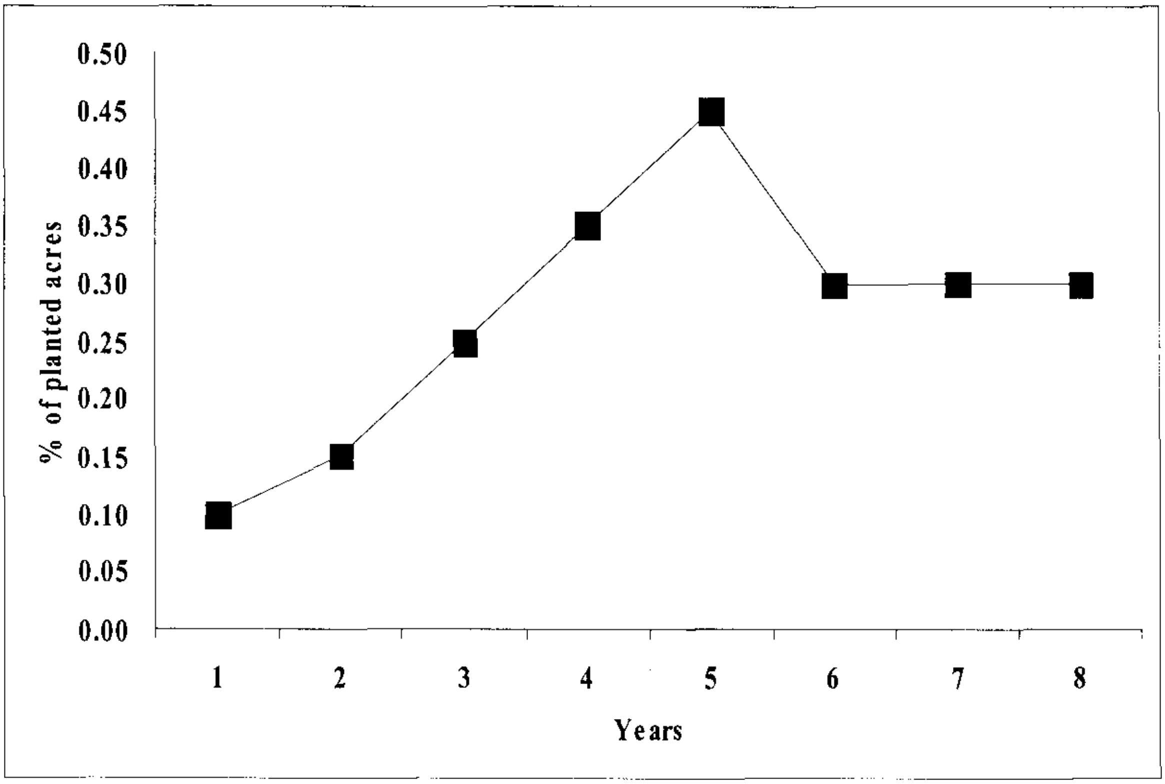

Figure 4.3. GM Trait Adoption Process.

A triangular distribution is placed on each year of post commercial adoption for the three GM traits. The triangular distribution specifies a minimum, most likely, and maximum case. The minimum and maximum are assumed to be 10 percentage points below and above the most likely case. For example, year five could have 35, 45, or 55% adoption.

Data for the development process were obtained from Monsanto (2004). Data include time to develop a GM trait and the cost per stage of development. Each development stage has a "known" development time, which is modeled as the minimum. Conversely, each stage has an "unknown" random time element, which is in addition to the minimum. The known and unknown development time for each stage are illustrated in Figure 4.4. The better the ability the firm has to manage the random elements of time, the more valuable the growth option. For example, the more time a firm must spend completing the regulatory process, the longer the delay to commercial development and release of the trait, causing a significant delay in cash inflows.

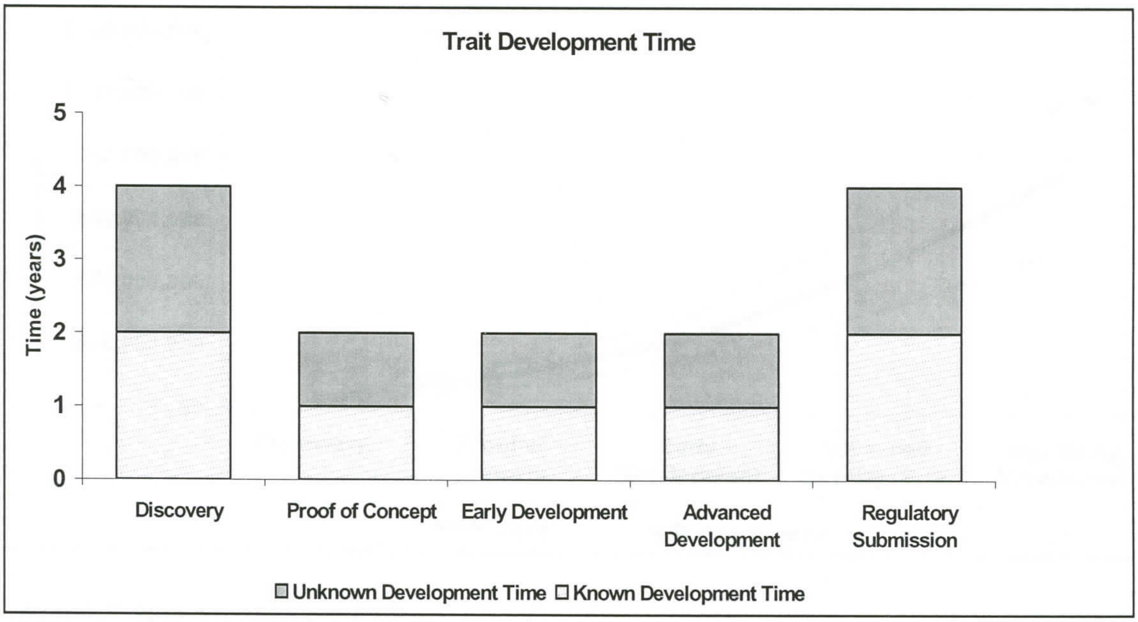

Figure 4.4. Trait Development Time.

The investments firms make in each stage of development is drawn from research results from Monsanto (2004). To our knowledge this is the only documented interpretation of the cost of trait development. The investment required for each stage increases for all subsequent stages. As with the element of time, the firm's ability to effectively manage cost will dramatically increase the value of the trait. Each stage has a minimum and maximum required investment. The early stages take less financial commitment, but are far less likely to succeed. Conversely, the later stages are more likely to succeed, but take greater financial commitment. Figure 4.5 presents the minimum, mean, and maximum investment path for developing a GM trait. In the base case, the cumulative cost of developing a trait is $76 million. In the best-case scenario, developing a trait costs $54 million, and the worst-case scenario costs $100 million. A risk uniform distribution is used to allow the investment cost for each stage to oscillate between the best and worst-case scenario.

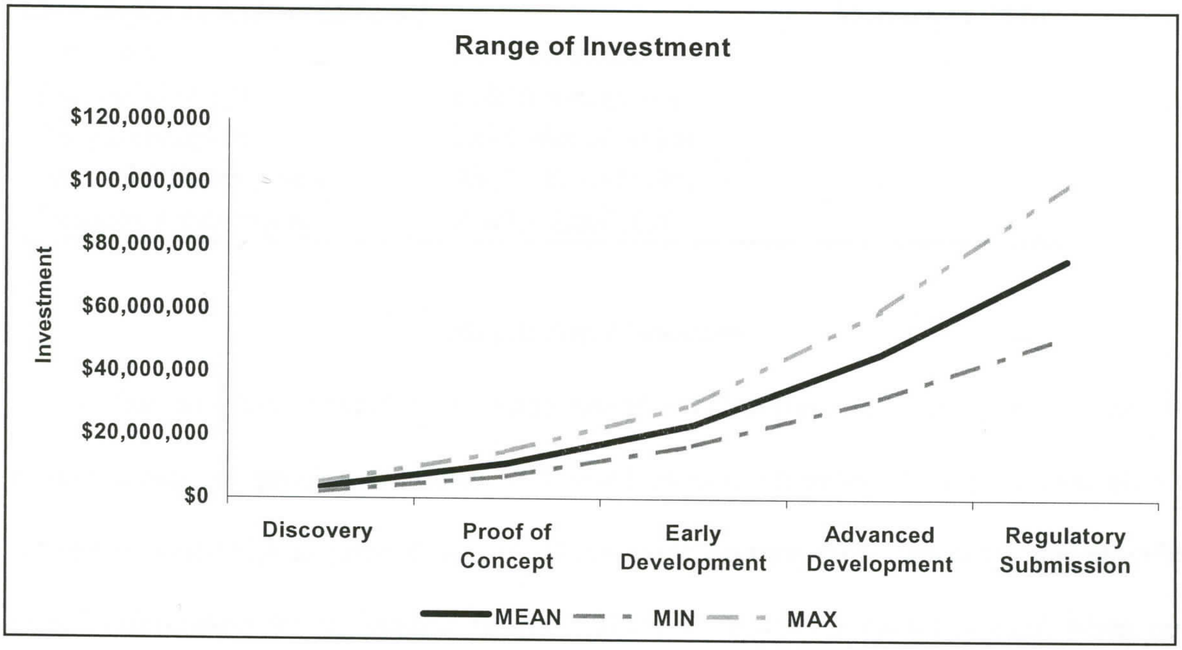

Figure 4.5. Investment Cost Path for GM Traits.

Table 4.3 summarizes the data sources and distributions used in the simulation model.

Table 4.3. Summary of Data and Distributions

Variables	**Distribution or Mean**	**Source**
Technology Fee		
Bt Corn	7.4*RiskTriang(0.9,1.0,1.1)	Duane Berglund
FR Wheat	12.4*RiskTriang(0.9,0.1,1.1)	
RR Wheat	5.1*RiskTriang(0.9,1.0,1.1)	
Planted Acres (millions)		
Bt Corn	MAX 79.1	USDA
FR Wheat	MAX 29.1	USDA,CGC
RR Wheat	MAX 29.1	USDA,CGC
Adoption Rate	RiskTriang(0.8,1.0,1.2)	
Time (years)		Monsanto (2006)
Discovery	RiskUniform(2,4)	
Proof of Concept	RiskUniform(1,2)	
Early Development	RiskUniform(1,2)	
Advanced Development	RiskUniform(1,2)	
Regulatory Submission	RiskUniform(2,4)	
Invesment in each phase (millions)		Monsanto (2006)
Discovery	RiskUniform(2,5)	
Proof of Concept	RiskUniform(5,10)	
Early Development	RiskUniform(10,15)	
Advanced Development	RiskUniform(15,30)	
Regulatory Submission	RiskUniform(20,40)	

Simulation Procedure

The analytical model is a mathematical relationship used, for given values of certain inputs, to provide solutions to desired outputs (Winston, 2001). However, in situations where risk is present, analytical solutions become more laborious and provide useful information for a decision maker. Thus, a simulation model is used when no tractable analytical model exists. A simulation model imitates a live situation while allowing the use of random variables when discrete variables are unknown or inconsistent with certain parameters (Winston, 2001). The simulation is performed on critical variables to determine their effect on the model outcome or how sensitive the outcome is to a given variable. The simulation provides decision makers with key information when deciding how to adapt to uncertainty.

Simulations use @Risk (Palisades, 2000). Probability distribution functions representing uncertainty are used to define the effect of random variables and entered into Excel spreadsheet cells instead of a formula or number. One thousand iterations are performed successively until distributions are filled and simulated results represent an accurate portrayal of a live situation. The scenarios are developed in Excel. The base case is developed to simulate the most likely event.

Sensitivities

Several assumptions are made in the base case. The random effects of adoption rates, technology fees, stage time, and salvage values are relaxed to examine the base case. Sensitivities are performed on the base case with these variables to see how they affect the value of the option. There are three planned sensitivities: adoption rate, technology fee, and the salvage value. Sensitivities are performed for FR and RR wheat.

Trait Adoption Rate

The first sensitivity analysis has been applied to adoption rate. The rate at which the new technology is adopted by consumers is the only measure of product demand. Historical data are available for adoption from the release of other traits such as Ht soybeans, Ht and BT corn, canola traits, and many others. The data clearly indicate that producers demanded traits that have already been released, but gives little indication regarding demand for unreleased traits, especially for crops consumed directly.

Because of the importance of trait adoption, numerous scenarios have been analyzed. The first scenario analyzes the best and worst case from the triangular distribution in the base case. These scenarios are critical to understand because management should know the value of the trait if demand reaches either extreme.

The second scenario analyzes changes in the adoption path relative to the traditional new product development cycle. First, adoption is strong early due to no competing technology, then adoption declines toward the end of the patent life as new entrants come to market. In the second sensitivity, slow emergence is followed by a rapid increase in adoption due to superior performance compared with competition from traditional varieties. The last scenario uses analytical values from Wilson (2006). Table 4.4 summarizes the adoption rate sensitivity scenarios.

Table 4.4. Summary of Adoption Rate Sensitivity

Sensativity	**Logic**	**Values (%)**
Scenario 1		
Best Case	Adoption reaches max value for all years	12,18,30,42,54,36,36,36
Worst Case	Adoption reaches min values for all years	8,12,20,28,36,24,24,24
Scenario 2		
Strong early	Strong early adoption, with a sharp decline due to new entrants	20,30,40,50,30,15,15,15
Strong late	Slow early adoption followed by a sharp increase in adoption due to product performance	5,10,15,15,40,50,50,50
Scenario 3		
Analytical rates	Equilibrium adoption rates for FR and RR wheat	FR = 34% RR = 90% domestic RR = 52% international

Technology Use Fee

The technology use fee is the market mechanism for determining the success of a trait and is management's primary response tool for handling competition and consumer demand. Acting as "price," the technology use fee can be adjusted to respond to either monopoly conditions or competing traditional varieties. The primary scenario of interest here is the effect on the trait valuation if a competing technology becomes available prior to commercial release of the GM trait. In this case, the technology use fee for FR wheat is lowered as a response to the release of a competing variety. The reduction will occur while the firm is in the advanced development stage of the process.

Salvage Value

It is quite clear that a firm's research and development projects are not independent of each other, but rather correlated in many respects. If one project is successful, correlated projects are also likely to have success. Additionally, there is value associated with failed scientific endeavor in the form of learning economies and potential spillover products. The salvage value, in this case, is the monetary value of learning and product offspring. A firm that invests in the discovery stage of developing a wheat trait is likely to have acquired basic knowledge, and should not have to repeat the entire process when investigating a new or improved wheat trait.

In the base case, the salvage value is assumed to be 35% of the cumulative investment of the development process. The first scenario investigates the worst-case scenario where there is no salvage value for failure. The second scenario analyzes option values when there are significant learning economies associated with failure.

CHAPTER 5
RESULTS AND SENSITIVITIES

Introduction

Not accounting for adaptability in the GM trait development process has implications for the research and development strategy of firms. These implications include the risk of investing in projects without considering the value inherent in acquiring new information. These errors in investment choice will drastically affect the long-term profitability of a firm because of the time, investment, and risk associated with developing a new trait.

This chapter presents the results from the base case as well as sensitivities for key option value drivers. It is organized into four sections. Section one highlights results in a general context for all examined traits. Then, option values are analyzed for each individual trait's risk and revenue profile. This allows decision makers to identify and rank worthy research and development opportunities. The third section provides sensitivities on stochastic option value drivers. Understanding the effect of key value drivers allows decision makers to better organize and control specific "events" in the timely investment process. Next, managerial implications are identified for the use of option valuation in the R&D process. A summary of the results is included in the final section.

Base Case Results

The results are explained in the context of entire analysis and then in further detail. First, the mean option value of the development process is identified (discover, proof of concept, early development, advanced development, and regulatory submission).

General Results

To begin, it is necessary to interpret the results provided in Table 5.1. Each development stage is considered a growth option. This is similar to a financial call option, where each subsequent option depends on reaching technical or commercial milestones from the previous stage. The BT corn development options are in the money at all stages of development because the value is >0. Thus, the option will be exercised and investment in development should be undertaken. Conversely, both FR and RR wheat exhibit out of the money options early in the development process where uncertainty is at its greatest. However, as early, more risky, milestones are met, uncertainty is resolved and the options are in the money.

Table 5.1. Mean Option Values by Stage and Trait

Stage	**Bt Corn**	**FR Wheat**	**RR Wheat**
Discovery	$527,984	-$2,040,872	-$4,506,523
Proof of Conept	$21,725,158	$4,918,615	-$12,181,622
Early Developm	$64,206,011	$25,487,167	-$15,255,430
Advanced Deve	$129,484,947	$62,472,373	-$9,888,810
Regulatory Subn	$207,619,805	$114,919,353	$12,835,223

Detailed Results for BT Corn

The model results for BT corn suggest that, given the potential cash flow, costs, and risks, investments should be made in the development and commercialization of the trait. The BT corn trait is ITM for almost the entire distribution of option results. By simulating these values, a range, min, max and distribution of the expected value is provided. From this, we can infer not only the min and max of the option value at each stage, but also the probability distribution. Table 5.2 presents the distribution of option values. The minimum option value for the discovery phase is -$3.8 million; however, all additional minimum option values for subsequent stages are in the money. The maximum option value for the discovery stage is $5.6 million, while the mean option value is $528,000.

Table 5.2. BT Corn: Distribution of Option Values

Stage	Minimum	Maximum	Mean	Standard Deviation
Discovery	-$3,759,217	$5,618,831	$527,984	$1,510,427
Proof of Conept	$1,848,215	$49,903,460	$21,725,158	$7,467,069
Early Development	$24,333,524	$125,023,480	$64,206,011	$16,494,629
Advanced Development	$59,370,252	$233,168,000	$129,484,947	$28,370,720
Regulatory Submission	$118,886,416	$344,729,504	$207,619,805	$37,605,494

Figure 5.1 presents the distribution of option values for the discovery stage of development for BT corn. For 2000 iterations, the option values for the discovery stage of development are out of the money 37.6% of the iterations, while in the money 62.4%. The distributions of option values for all subsequent stages are in the money (ITM) 100% of the time. Thus, from these results, it is possible to conclude that at the discovery phase, the probability of a positive value of the option is .624.

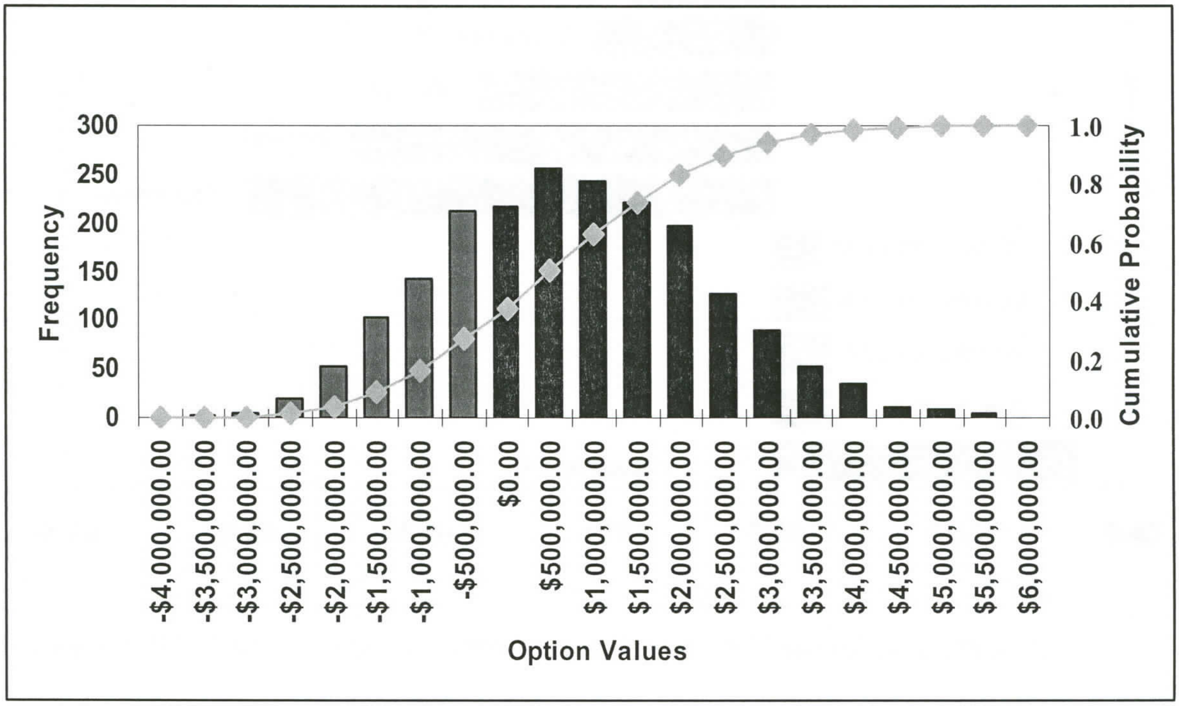

Figure 5.1. BT Corn: Distribution of Option Values for the Discovery Phase.

Figure 5.2 presents the correlation between the option value for the discovery and various random input variables. The greatest single impact on the option value at the discovery stage is the investment costs required to reach the technical milestones needed to continue to the proof of concept stage. The correlation coefficient for Investment D is negative 0.60. (Therefore, for every 1% increase in Investment D, the value of the growth option responds by going down 0.60%.). Additionally, the time it takes to complete the regulatory submission stage and the advanced development stage impacts the value of the growth option negatively. The logic behind this result is sound because the uncertainty of developing a trait has largely been resolved by the advanced development stage, and the longer stages take to complete, the more impact the time value of money will have on the option value.

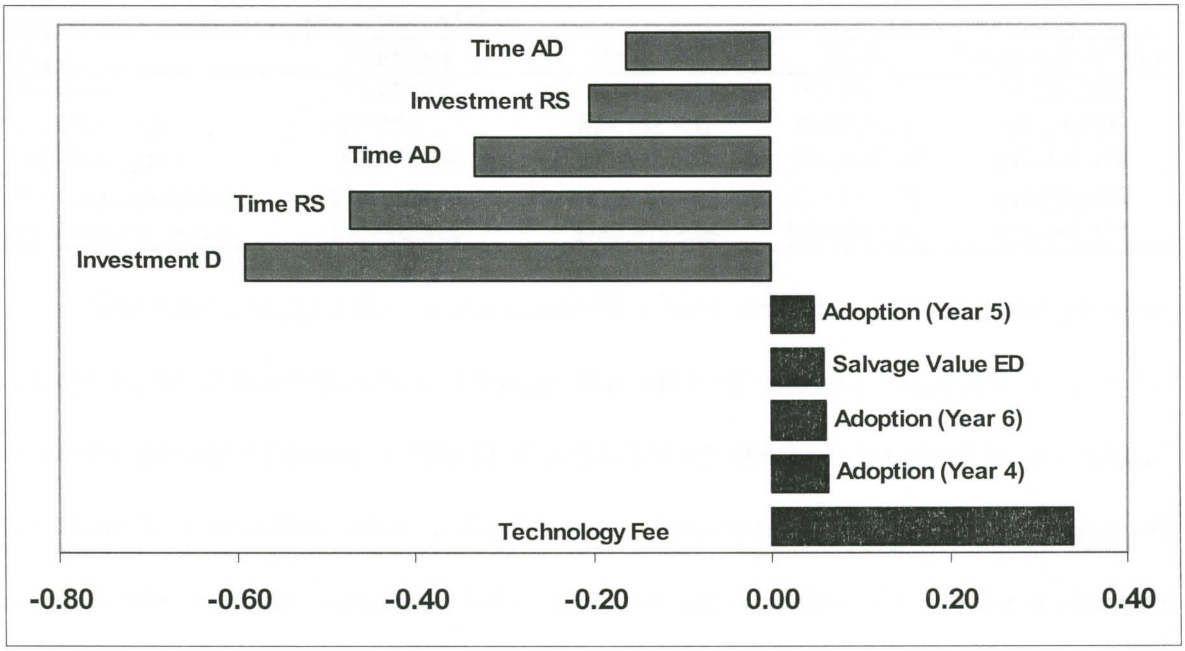

Figure 5.2. BT Corn: Correlation Graph for the Discovery Phase of Development.

Detailed Results for FR Wheat

The option results for FR wheat, under base case assumptions, suggest that the risk attributes and investment costs exceed potential revenue. Through simulation, we can derive the mean value as well as the range and distribution. The mean option value at the discovery phase is OTM at negative $2 million dollars, which ranges from -$5.4 to $1.5 million. The real growth option for FR wheat at the discovery phase of development is in the money at a probability of 4%. Option values improve if the firm is able to complete the technical milestones associated with the discovery phase of development. The distribution of option values for the proof of concept phase shows the mean option value at $5 million, and option values increase, as uncertainty is resolved and technical milestones are met as illustrated in Table 5.3.

Table 5.3. FR Wheat: Distribution of Option Values

Stage	Minimum	Maximum	Mean	Standard Deviation
Discovery	-$5,409,771	$1,535,147	-$2,040,872	$1,184,281
Proof of Conept	-$10,355,271	$20,173,706	$4,918,615	$4,851,085
Early Development	-$3,799,164	$58,905,424	$25,487,167	$10,408,370
Advanced Development	$14,665,394	$120,638,896	$62,472,373	$17,760,455
Regulatory Submission	$52,002,468	$188,475,936	$114,919,353	$23,287,557

The results suggest that as the uncertainty involved in the discovery and proof of concept phase of development is resolved, the value of the trait increases. Figure 5.3 shows the percent of option values ITM and OTM by development stage for FR wheat. More than 95% of option values in the discovery phase are OTM. This can be interpreted as, given the base case variables, 95% of investment scenarios will present a situation where management will not exercise the option to enter the follow-up investment for the proof of concept phase.

The option values for the proof of concept phase are OTM for 15% of the investment scenarios. Therefore, 15% of the time, decision makers would not exercise the option to invest in the early development phase. The FR wheat trait has a 4% chance of being ITM following the first two phases of development.

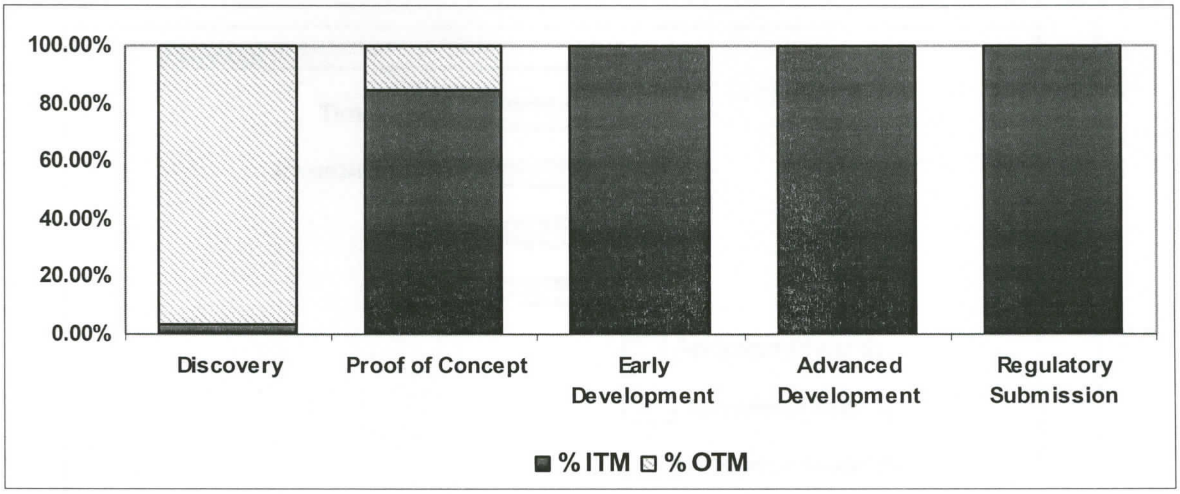

Figure 5.3. FR Wheat: Percent of Options ITM by Development Stage.

In the development of FR wheat, the investment in the discovery phase has the greatest impact on the option value of the discovery phase. For the base case, the investment function for the discovery phase ranges from $2 million to $5 million. For every 1% increase in the investment cost in the initial stage, the option value decreases 0.8%. The second greatest impact on the option value is the time it takes to complete the regulatory phase of development. It takes one to three years to complete regulatory submission, and for every additional 1% of time, the option value declines 4%.

The ability of the agbiotechnology firm to charge a technology use fee (TUF) for its GM trait has the greatest positive impact on the real option value. The base case assumes a minimum TUF for FR wheat of $9.88/acre and a maximum of $14.82/acre. If the firm is able to increase the technology fee 1%, the corresponding increase in the option value is 0.3%. For example, if the firm is able to increase the TUF to the maximum from the minimum the value of the option is expected to increase 13%. The second greatest positive impact is the salvage value of the research and development work completed in the discovery phase. Figure 5.4 illustrates the key value divers for the FR wheat option values.

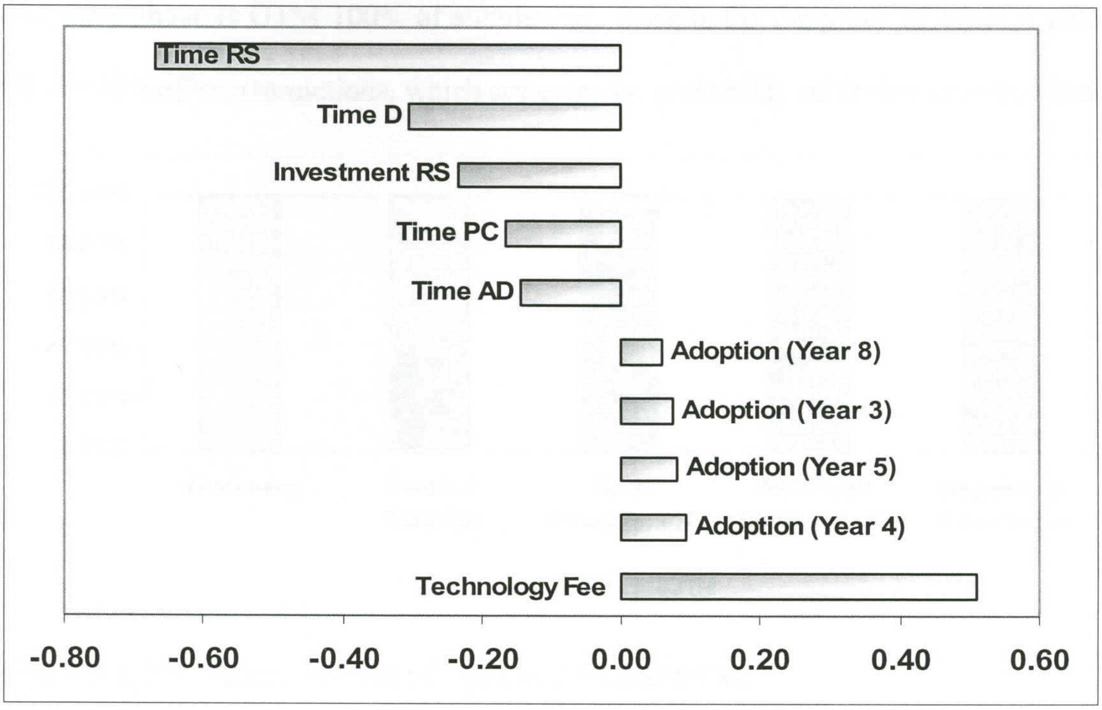

Figure 5.4. FR Wheat: Impact of Key Option Value Drivers.

Detailed Results for RR Wheat

Considering the results of the base case, investment in the development of RR wheat would be speculative at best. The distribution of option values for RR wheat is presented in Table 5.4. The mean option value for the discovery phase is negative $4.5 million, ranging from a minimum of negative $7 million to negative $2 million. As with BT corn and FR wheat, option values increase as technical milestones are met in the discovery and proof of concept phase.

Table 5.4. RR Wheat: Distribution of Option Values

Stage	Minimum	Maximum	Mean	Standard Deviation
Discovery	-$7,072,768	-$2,021,312	-$4,506,523	$1,121,872
Proof of Concept	-$19,644,114	-$4,650,105	-$12,181,622	$4,161,506
Early Development	-$27,073,400	-$2,312,599	-$15,255,430	$8,727,718
Advanced Development	-$30,646,358	$10,160,423	-$9,888,810	$14,830,301
Regulatory Submission	-$9,295,200	$39,719,436	$12,835,223	$19,288,806

Figure 5.5 illustrates the risk of investing in the development of RR wheat. Through simulation we derive the mean value, as well as the range and distribution. The discovery phase is OTM 100% of simulations. Results for the proof of concept phase are OTM 100% of the simulations, which suggests the probability of further investment is nil.

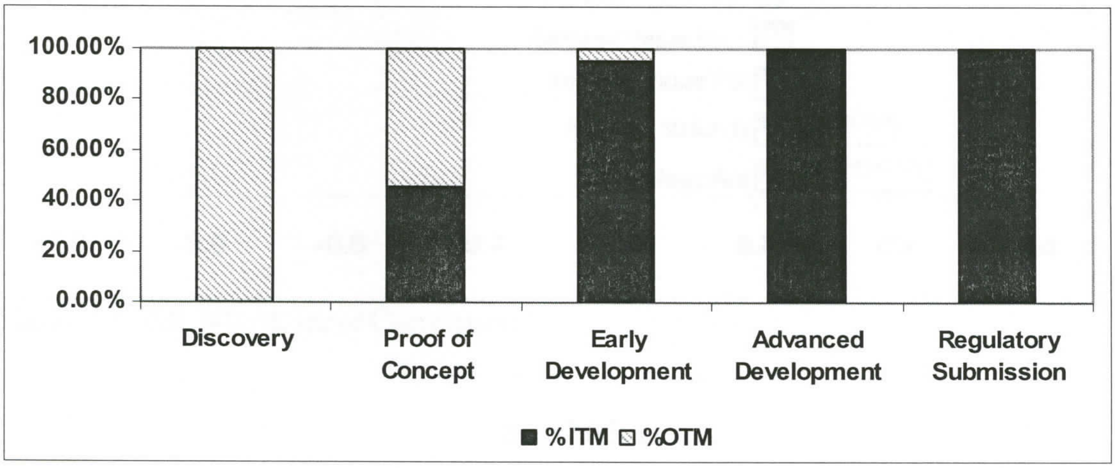

Figure 5.5. RR Wheat: Percent of Options ITM and OTM.

As with FR wheat, investment in the discovery phase has the greatest impact on the real option value. The negative correlation between investment in the discovery phase and the option value is –0.8. Secondly, a 1% increase in the regulatory submission phase will decrease the option value 0.3%. The TUF has the greatest impact on the upside. A 1% increase in the TUF will result in a 0.3% increase in the option value. Additionally, the ability to recapture a salvage value in the discovery, proof of concept, and early development phases all contribute to upside potential in the option value. Figure 5.6 displays the key positive and negative input correlations to the RR wheat option value.

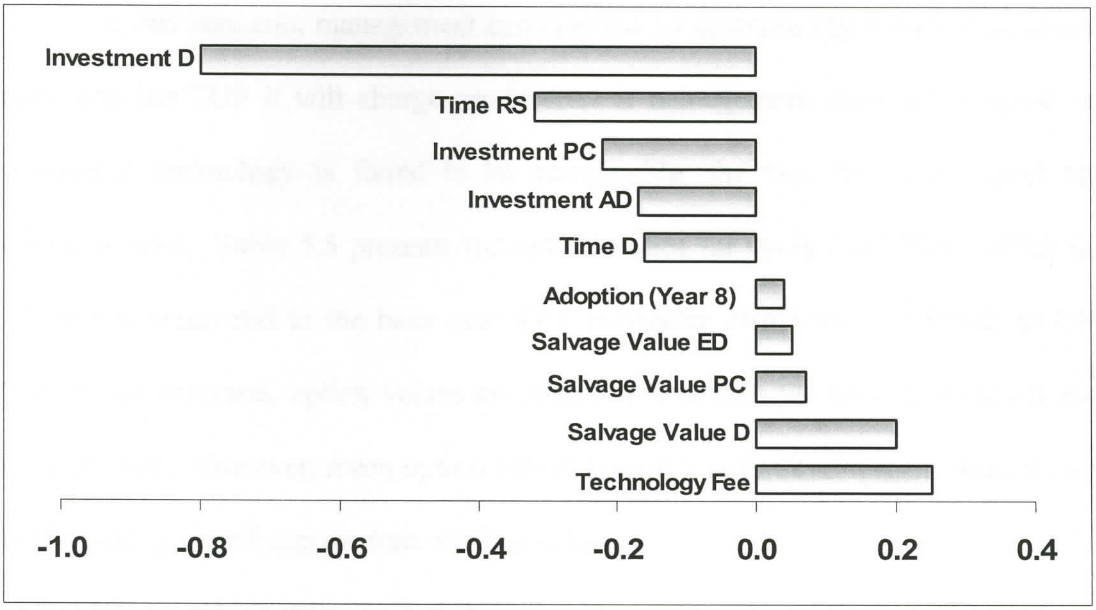

Figure 5.6. RR Wheat: Input Correlation

Sensitivities

Stochastic variables are used to demonstrate risks that are present in valuing the development of a GM trait. Sensitivities are performed on three important variables. These include technology-use-fee (TUF), adoption rates, and salvage value. The sensitivities are evaluated, in some cases on all three GM traits, but most of the focus is paid to FR wheat.

The Technology Use Fee

The technology use fee (TUF) is management's primary response mechanism to changes in market dynamics. If, during the development process, competition enters the market, management can adapt the real options model to better represent market conditions. For example, the development of FR wheat has completed the discovery through early development stages, and is nearing the completion of advanced development. While completing the advanced development stage, the market dynamics have shifted due to the anticipated release of a traditional variety that is designed to resist fusarium head blight.

In this scenario, management can respond by dramatically reducing its assumption regarding the TUF it will charge producers. If management does not respond, and the competing technology is found to be comparable, the GM trait can expect sluggish adoption rates. Table 5.5 presents the option values for "very low" TUF, which is set at $7.50/acre compared to the base case TUF triangular distribution of $9.92, $12.40, and $14.88. As expected, option values are sharply lower than the base case for all stages of development. However, mean option values from the early development stage forward are in the money, signifying the trait still has value.

Table 5.5. FR Wheat: "Very low" TUF option values vs. base case values

Stage	Response Price	Base Case
Discovery	-$3,732,957	-$2,040,872
Proof of Concept	-$5,952,993	$4,918,616
Early Development	$470,453	$25,487,168
Advanced Development	$19,117,536	$62,472,373
Regulatory Submission	$54,881,337	$114,919,354

The iterative process of the simulation reveals that only 50% of the iterations for the early development process are in the money, while 100% are in the money for advanced development and regulatory submission. Figure 5.7 shows the in the money path relative to the mean option values presented in Table 5.5. Because the scenario assumes the firm is in the advanced development stage, the decision criteria is based on that point of the option path. The mean option value, although 50% less than the base case, is in the money; therefore, the firm should exercise the option to move to the regulatory stage of development.

The firm has resolved the technical risk associated with the first three stages of development, and the investment made in those stages are sunk and not considered in subsequent stages. If the firm were in the discovery stage or the proof of concept stage of development, they would not exercise the option but would abandon development and receive the salvage value.

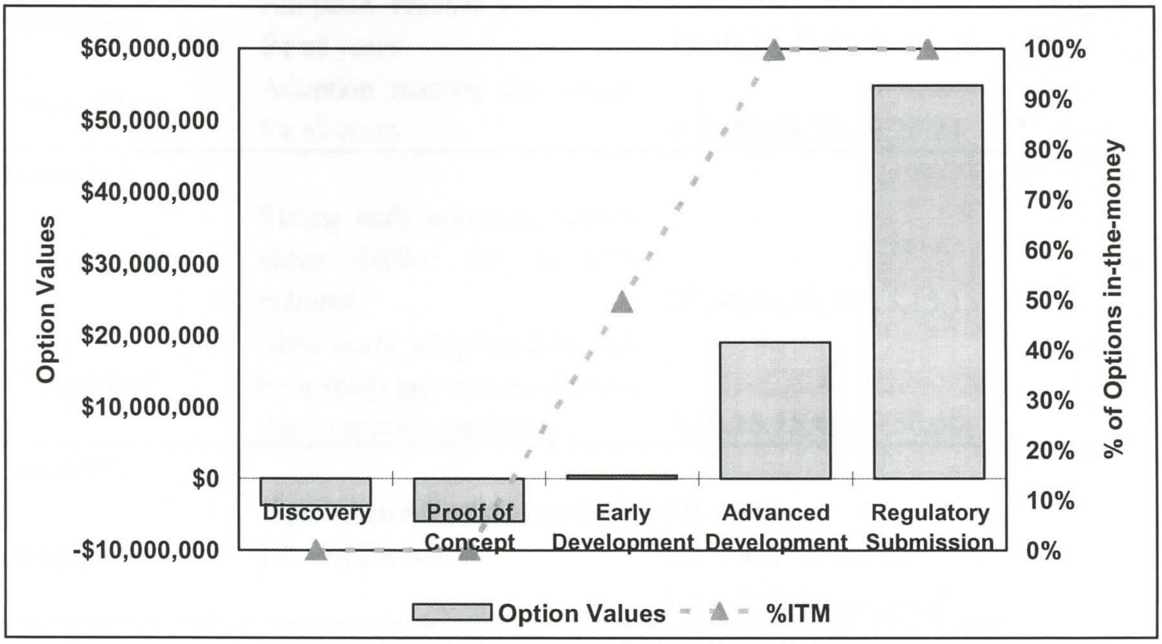

Figure 5.7 FR Wheat: "Very Low" Option Values and Percent of Iterations ITM

<u>Adoption Rate</u>

The following presents sensitivity analysis on the adoption rate of RR and FR wheat traits. The base case model assumes a traditional adoption cycle of new technology, with adoption starting slow in the initial commercialization phase, then picking up in the middle, followed by slow declines during the mature phase of the new technology. Table 5.6 presents the three scenarios that are analyzed for the adoption rate sensitivity. The first scenario will analyze the best and worst case scenario of the triangular distribution of the base case.

Table 5.6 Summary of Adoption Rate Sensitivity

Sensativity	Logic	Values (%)
Scenario 1		
Best Case	Adoption reaches max value for all years	12,18,30,42,54,36,36,36
Worst Case	Adoption reaches min values for all years	8,12,20,28,36,24,24,24
Scenario 2		
Strong early	Strong early adoption, with a sharp decline due to new entrants	20,30,40,50,30,15,15,15
Strong late	Slow early adoption followed by a sharp increase in adoption due to product performance	5,10,15,15,40,50,50,50
Scenario 3		
Analytical rates	Equilibrium adoption rates for FR and RR wheat	FR = 34% RR = 90% domestic RR = 52% international

As a starting point, developing a range of possible outcomes is useful for forming expectations. In the first scenario of adoption rate sensitivities, the best and worst case scenarios are analyzed to develop extreme outcomes. Figure 5.8 provides a graphical representation of the possible range of outcomes given extreme adoption rates to the low and high end for FR wheat.

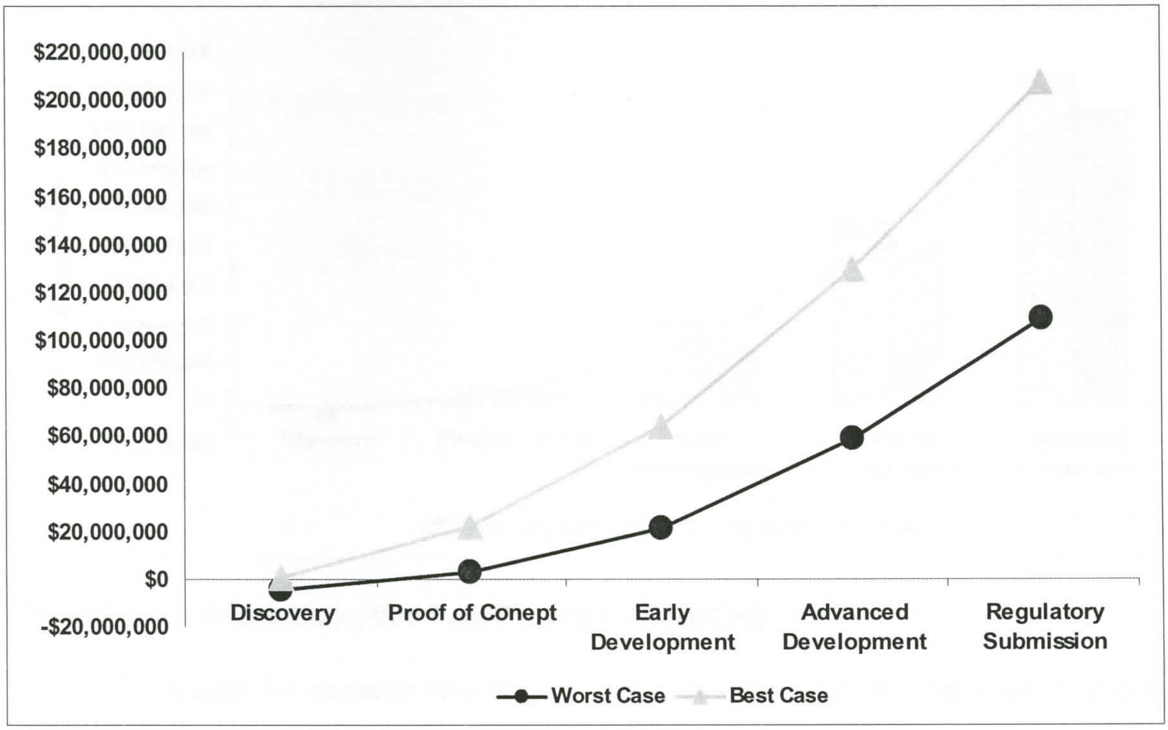

Figure 5.8. FR Wheat: Best and Worst Case Adoption Rates.

Scenario 2 presents two possible adoption paths that should be considered when developing a real options model for a GM trait, in this case FR wheat. The first possible path exhibits strong early adoption, with a sharp decline due to new competition prior to the end of patent. The second path considers slow early adoption followed by a sharp increase in adoption due to superior product performance.

The results show that strong early adoption and slow deterioration is superior to strong late adoption as well as the base case. Figure 5.9 shows that option values for the "strong early" path exceed the other two paths for all stages of development. For the discovery stage, the option value for "strong early" is -$1,704,343, compared to -$2,095,054 for the "strong late" path and -$2,040,872 for the base case. The margin grows to $14 and $12 million for the regulatory stage, respectively.

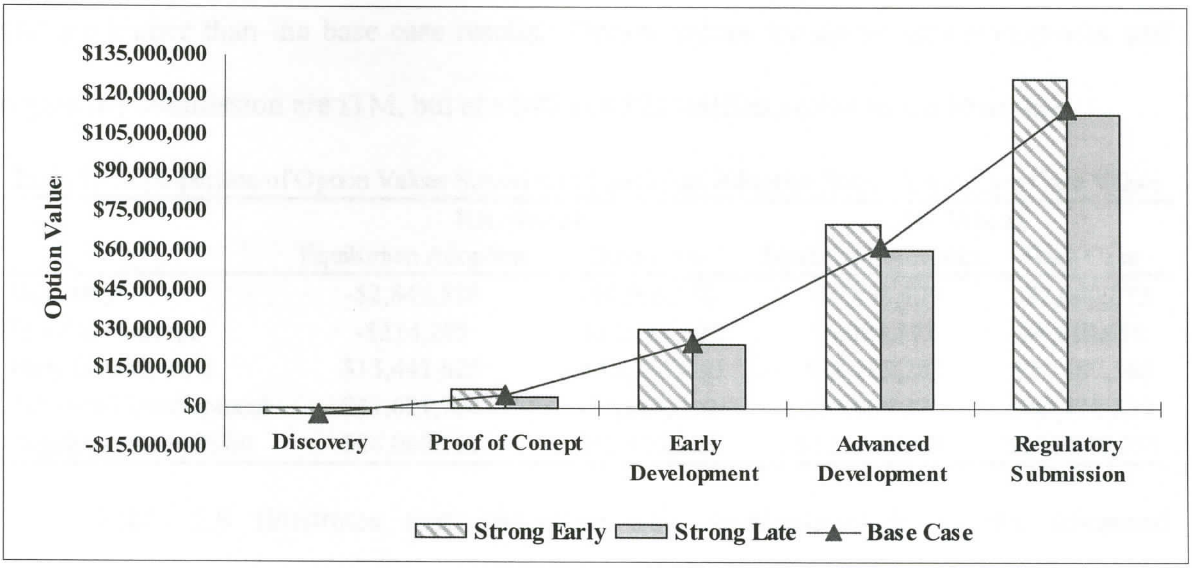

Figure 5.9. FR Wheat: Adoption Path Results vs. Base Case.

The results for scenario two suggest that a strategy of additional marketing costs during the regulatory stage to maximize early adoption may be more critical than the additional investment in producing a "superior" performing product. This is especially true if there is greater potential for rival products to enter the market later in the life of the patent.

Scenario three presents option values derived from the equilibrium max adoption rate for FR and RR wheat. The equilibrium adoption rate for FR wheat is 34%, while adoption rates for RR wheat are 90% domestic and 53% international (Wilson, 2005). The adoption will start slow, as with traditional models, but will reach the equilibrium rate in revenue year three. Equilibrium will be maintained for the life of the patent.

Table 5.7 illustrates the option values derived using the equilibrium adoption rates versus base case results. The value of developing RR wheat is universally higher when using the equilibrium adoption rates. The discovery and proof of concept phase are OTM, and are higher than the base case results. Option values for advanced development and regulatory submission are ITM, but at a $40 and $29 million deficit to the base case.

Table 5.7. Comparison of Option Values Solved with Equilibrium Adoption Rates Versus Base Case Values

	RR Wheat		**FR Wheat**	
	Equilibrium Adoption	Base Case	Equilibrium Adoption	Base Case
Discovery	-$2,849,528	-$4,506,523	-$1,858,179	-$2,040,872
Proof of Concept	-$314,285	-$12,181,622	$6,094,371	$4,918,616
Early Development	$13,441,628	-$15,255,430	$28,185,287	$25,487,168
Advanced Development	$41,621,704	-$9,888,810	$67,009,375	$62,472,373
Regulatory Submission	$86,060,133	$12,835,223	$121,149,679	$114,919,354

Table 5.8 illustrates that, assuming trait development is in the advanced development stage, RR wheat has significant value. Options are in the money 100% of iterations for the advanced development and regulatory submission stage.

Table 5.8 RR Wheat: Detailed Equilibrium Adoption Sensitivity Results

Stage	**Minimum**	**Maximum**	**Mean**	**OTM**	**ITM**	**%ITM**
Discovery	-$2,418,273	$756,480	-$5,278,267	1987	13	1%
Proof of Conept	$346,313	$13,360,749	-$11,993,401	961	1039	52%
Early Development	$13,389,535	$43,231,064	-$9,632,302	97	1903	95%
Advanced Development	$39,711,048	$89,692,360	$2,407,037	0	2000	100%
Regulatory Submission	$81,955,472	$143,342,544	$33,794,192	0	2000	100%

Salvage Value

The final sensitivity compares option values when FR wheat has either no salvage value or a salvage value of 50% of the cumulative investment and compares the results to the base case. Option values drop significantly when no salvage value is available in the case of failure. The option value in the discovery stage is $1.0 million less than the base case and $5.5 million less than option values when the salvage value is high. Table 5.9 illustrates the option value at each stage for the no salvage value and high salvage value sensitivities against base case results.

Table 5.9 FR Wheat: Salvage Value Sensitivity

Stage	No Salvage Value	High Salvage Value	Base Case
Discovery	-$3,110,662	$2,620,228	-$2,040,872
Proof of Concept	$2,490,932	$11,370,699	$4,918,616
Early Development	$22,985,326	$34,229,626	$25,487,168
Advanced Development	$61,281,283	$71,092,774	$62,472,373
Regulatory Submission	$115,816,562	$122,407,409	$114,919,354

Managerial Implications

This chapter has applied the real options methodology to three GM traits; one trait is commercially available, and the other two are currently suffering the same fate. If the real option value exceeds zero, the trait developer should invest, otherwise the project should be deferred. Both FR and RR wheat traits have accomplished the technical milestones and have succeeded in creating demand from producers but have not been able to complete the required marketing and regulatory requirements for commercial release and subsequent production. No matter how technically sound a new technology, the marketing and regulatory structure requirements are time consuming and expensive.

There are several variables in the real options model that affect the value of GM trait development. The time element of the model, especially the regulatory submission stage, has a strong impact on the value of the GM trait. The correlation coefficient for the time it takes to complete regulatory submission ranges from -0.32 to -0.60. Therefore, management's ability to properly prepare and complete the regulatory hurdle will greatly increase the value of the GM trait. Alternatively, the technology use fee has the greatest positive impact on the value of the GM trait with the correlation coefficient ranging from 0.35 to 0.50.

There are numerous results and sensitivities, but three key results require further consideration: first, the option values for RR and FR wheat have negative values in the early development phases; second, despite the negative option values in the discovery phase, trait developers pursued development; and third, the BT corn trait returns a very large option value relative to other traits examined.

The present value of the project cash-flows is a function of the rate at which the technology is adopted, market size, and the technology-use-fee received per acre. Both RR and FR wheat were developed for spring planted hard wheat, which only accounts for around 43% of the United States and Canada's planted acres. The risk, investment, and time required to develop a single GM trait are so great that, to be worthwhile, the trait must be able to occupy substantial acreage.

Consequently, investment in both of these traits was made despite negative option values in the early stages of development. It is likely that the major constraints of time and cost in the regulatory submission stage exceeded expectations. The development and commercial release of previous GM traits provide the guidance for time and cost estimates, but developers failed to recognize the consumer resistance to the release of a GM food trait compared to traits used for oil content or animal feed.

Option values for BT corn are very large compared to RR and FR wheat traits for numerous reasons. The United States corn market is nearly 80 million acres providing a more than adequate market size for GM seed. Unlike wheat, where there are six classes with very different characteristics, corn is largely the same for all acres and production allowing GM traits to have wider appeal. The profitability of GM corn has led to competition to produce stacked traits with numerous agronomic enhancements to capture segments of the market.

The model results imply numerous critical elements that firms should consider when making GM trait investments. First, traits developed for a narrow market will most certainly be less valuable than traits with wider appeal. Examples would be traits with international appeal, such as drought resistance or a trait with an increased nutritional profile. Secondly, it is clear that reducing the time it takes to complete the regulatory submission stage will add substantial value to a GM trait. Traits used for feed and oil content have been more successful in completing the final stage of development.

CHAPTER 6
SUMMARY AND CONCLUSIONS

Review of Problem

Strategic planning and investment are critical functions in the operation and profitability of a business. The ability of firms to invest in and introduce new and useful products to market determines success and failure. Agbiotechnology companies are tasked with selecting, from thousands of crop and trait combinations, a new trait that is technically feasible and will meet the requirements of regulators and the demands of producers and consumers. The process is rife with endogenous and exogenous risk. Early in the development process, numerous technical uncertainties must be resolved, and, later in the process, market and political uncertainties take center stage. Traditional valuation methods lack the ability to value management's ability to reverse course as market dynamics shift.

In contrast to real assets and real commodity options, it is difficult to accurately predict discoveries or estimate future unit sales of research and development products. High risk and intense competition impose the use of real options analysis to evaluate risks and aid in the ranking and selection of research and development projects. The high levels of volatility of research and development outputs positively influence the value of the option because high returns can be generated and low returns can be avoided by reacting to changing conditions.

The real options approach provides a way of modeling uncertain values underlying the investment in a GM trait. In the case of trait development, the unknown values are the expected cost of completion and the expected cash flows after commercialization.

The first element of uncertainty is the cost of developing a new trait and the technical and regulatory requirements to bring the trait to market. Each stage in the development process has specific cost and risk attributes that are dependent on the characteristics of the individual trait.

The second source of uncertainty is expected cash flow in post-commercialization. The trait developer must be able to accurately forecast product demand based upon domestic and international adoption rates. Understanding both sources of uncertainty is needed to develop an accurate valuation framework.

Objectives

The objective of this research is to develop a model for valuing and ranking GM traits using the real options approach. Specific objectives are to (1) evaluate the risk and reward profile of developing a GM trait including historical demand and industry structure; (2) evaluate traditional valuation methods to identify advantages of using the real options approach; (3) develop a real options model to value the GM trait development process; (4) analyze key option drivers to determine relationships between stochastic variables and real option value; and (5) apply the model to three GM traits: BT corn, FR wheat, and RR wheat.

Procedures

In this thesis, a discrete event simulation is used to analyze the real option value of each stage of developing a GM trait. Literature on biotechnology, research and development, and real options methodology are used to develop a general model of the risk and reward profile of the trait development process. The model is designed in a Microsoft Excel format compatible with the analytical software Palisades @Risk. The simulation model contains distributions to represent the stochastic variables associated with the development process and the post-commercialization revenue model.

The model follows a four-step process that allows the use of risk-neutral analysis to solve the binomial option model. In the first step, all option drivers are mapped along an option tree. In the second step, calculations are done in order to solve the inner nodes of the option tree through backward induction. In the third step, single period probabilities are converted to risk-neutral probabilities in order to allow the use of the risk-free rate of interest. In the last step, backward induction is repeated, but this time using the risk-neutral probabilities and the risk-free rate of interest.

Sensitivity analysis is conducted to reflect the influence certain parameters have on the real option value. The technology use fee is selected because it is management's primary tool in responding to changes in market dynamics. The second sensitivity is designed to measure the effect of numerous possible scenarios in the demand parameter. Many adoption rate paths are examined to determine the effect of demand shifts on the value of the option. The last sensitivity is applied to the salvage value to measure the effect of research diversity. It is assumed that if a firm has a diverse research and development policy, failure will result in a higher salvage value. Conversely, when a firm has an all-or-nothing trait development policy, the salvage value is considered nil.

Review of Results

Real options analysis and simulation of stochastic variables are used to value the development and commercialization of a GM trait. The model is an extension of Jagle (1999), who developed a real options model for a "new product development" case study. The development of a GM trait is identified as a growth option because of the various milestones required to reach each subsequent stage of development. The development variables are mapped along a binomial option tree. Each stage has two possible outcomes:

success or failure. If the phase is deemed successful, development will advance to the following phase; if the phase is deemed a failure, then the growth option is not exercised, and the investment is deferred. The model is extended to three GM traits: BT corn, RR wheat, and FR wheat.

Base Case Results

The main benefit of base case results is to set the stage for later sensitivities. However, the base case results did provide valuable information for each trait. The base case model assumes the most likely scenario, while allowing random variables to oscillate within a predetermined range of values.

Option values for the three traits analyzed differ greatly. The BT corn development options are in the money at all stages of development because the value is >0. Therefore, the results suggest that, given the potential cash flow, costs, and risks, investment should be made in the development and commercialization of BT corn.

Alternatively, option values for FR wheat are out of the money in the discovery stage of development and in the money for all subsequent stages. The mean option value for the discovery stage is -$2 million. Therefore, given the risk and reward profile, investment in FR wheat should be deferred. However, because trait developers have initiated investment and are in the advanced development stage, it is important to analyze option values for that specific stage. Option values for FR wheat at the advanced development stage range from $15 million to $121 million, with a 100% probability of the option being in the money.

RR wheat has similar results, but option values are out of the money for the discovery stage through advanced development stage. Option values for the early development stage range from -\$7 million to -\$2 million, with a 100% probability of the option being out of the money. As with FR wheat, investment in RR wheat has already been initiated and is stalled in the regulatory stage of development. Option values range from -\$9 million to \$40, with a 78% probability of the option being in the money. Therefore, the option to commercialize RR wheat should be exercised because, at this point, most of the cost has been incurred and uncertainty resolved.

Detailed Results and Significant Findings

Analysis of base case results and sensitivities make clear a few critical trends. The following section will highlight these trends and identify specific implications:

- For all three traits, the time element in the regulatory stage is negatively correlated with the real options value. The correlation ranges from -0.5 to -0.8, which indicates a small increase in time will significantly reduce the value of the option.
- The ability of the firm to maximize the technology use fee has the greatest positive impact on the value of the option. The technology use fee has a positive correlation from 0.25 to 0.40. Additionally, the sensitivity for a sharp reduction in the technology use fee as a response to competition from a traditional variety for FR wheat reduces the mean option value in the advanced development stage to \$19 million from a base case value of \$62 million.
- Base case results clearly indicate that GM traits developed for crops with larger market size and wider appeal are more likely to succeed. Highly specialized traits for narrow markets certainly will impact the option value negatively.

- Results indicate that strong early adoption has a greater impact on option values than strong late adoption.
- The ability of the firm to capture a salvage value has a positive impact on the value of the option. Option values where the salvage value is 50% of the cumulative investment are far higher, especially in the early stages of development, than when the firm receives no salvage.

Implication of Results

Previous studies analyzed the optimal time to release GM wheat from the perspective of government. The option to license the trait was characterized as a timing option, which occurs when the decision maker has the option to delay the investment. This research focuses on the valuation of a GM trait in the context of firm strategy. The research and development option is modeled as a growth option because each stage has a set of milestones that must be completed before moving on to the next stage.

Consideration to market size and scope of the GM trait are critical elements to investment selection. RR and FR wheat appeal to a very narrow market, which significantly limits post-commercialization cash flow. On the other hand, BT corn has a very large market and is widely adaptable to most of the available acres, creating significant potential cash flow.

By keying in on critical value drivers, managers can increase the value of the GM trait. The most important factor is the time it takes to complete the regulatory submission stage. Traits used for feed and oil content have been more successful in completing the final stage of development. Additionally, the investment requirements in regulatory stage are large, but have very little impact on the value of the growth option. Therefore, managers should be willing to make a trade-off by investing more in the marketing and regulatory approval process to minimize the time spent in the final stage.

Limitations of Study

This research serves as a general real options methodology for valuing the development of a GM trait. Relationships between time, investment, demand, and price with the option value of the trait are captured. There are some limitations that restrict its real world application.

The data used in the research have limitations. All the data for the development process, including investment, time, and probability of success, are taken from results of Monsanto trials. Many firms are unable to match the size and resources of Monsanto; therefore, these variables are likely to be on the high end of the distributions provided.

Additionally, crop and trait specific data would improve the results. For example, the model assumes the time, cost, and probability of failure in the discovery phase are the same for all three traits. Clearly these variables would be higher given the genetic complexity compared to corn or soybeans.

Need for Further Research

This research serves as an exploration of real option methodology as it applies to the valuation of the GM trait development process. However, there are aspects of the trait development process that should be expanded further.

In this research, it is assumed that to develop a GM trait, firms must complete all five stages of development. However, firms could develop many traits following the completion of the discovery and proof of concept stages. If this were the case, option values would be higher because the cost and time of development would be lower, and a significant amount of uncertainty would already be resolved

A second area of additional research could be the inclusion of revenue from follow on sales. For example, the development and release of RR wheat is designed to increase the sales of the RR herbicide. Including the expected increase in herbicide sales will increase the growth option value. This situation relates to a compound option where the value gained from increased herbicide sales depends on the value trait development process being in the money.

Summary

This research has explored the valuation of developing a GM trait using the real options approach. Increased global demand for commodities has led to the need for new and innovative methods of increasing agricultural productivity. Firms have an excellent opportunity to capture the value of these future opportunities, but they must adequately account for the uncertainty associated with developing a new trait. The real options approach will account for these uncertainties and improve the ability of firms to rank and select the most profitable traits.

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